

Ned H. Burns Symposium on Historic Innovations in Prestressed Concrete

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American Concrete Institute®
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SP-231

First printing, October 2005

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Printed in the United States of America

Editorial production: Lindsay K. Kennedy

Library of Congress catalog card number: 2005933692

ISBN: 0-87031-192-1

Preface

This Special Publication of the American Concrete Institute consists of papers accepted for the *Ned H. Burns Symposium on Historic Innovations in Prestressed Concrete*. The included papers were presented in two sessions sponsored by Joint ACI/ASCE Committee 423 at the ACI Fall 2005 Convention. In accordance with standard ACI review procedures, all papers were peer reviewed by at least two experts in the subject area.

The collection of papers in this volume presents a range of topics describing historic innovations in prestressed concrete over the past half-century. Topics include early uses of prestressed concrete by industry pioneers in Europe and the United States, development of construction techniques and design standards for several different prestressed concrete applications, and the use of innovative modern materials such as self-consolidating concrete and fiber-reinforced polymers.

Although the prestressed concrete industry is less than a century old, there have been several true pioneers who have helped develop and promote the use of prestressed concrete through research and teaching. Dr. Ned H. Burns has certainly earned his place in this group by making extensive contributions to the industry over the past five decades. Dr. Burns has completed extensive research on a number of topics related to prestressed concrete—design of unbonded tendons, bond of prestressing strand, prestressed concrete pavement, and the use of high-strength concrete among them. He is a long-time member and former chair of Joint ACI/ASCE Committee 423, a member of the National Academy of Engineering, and the co-author of a widely used text on prestressed concrete with T.Y. Lin.

Through the years, Ned Burns has touched the lives of hundreds of students coming through the structural engineering programs at The University of Texas at Austin. As a teacher, advisor, Graduate Student coordinator, Director of Ferguson Structural Engineering Laboratory, and Associate Dean for Academics, Dr. Burns has consistently inspired students with his blend of academic excellence and personal attention. Universally, we have come to know Ned Burns as the personable, unflappable, amiable, and endearing professor that was always interested in a student's life outside of work and his or her family, hobbies, and interests. In short, Ned Burns was always genuinely interested in the other person—an interest born of faith in God and a heartfelt concern for other people and their life circumstances.

In penning this preface, we were challenged with a very difficult task—to capture the essence of a man who was elected to the National Academy of Engineering by virtue of an academic career of leadership and accomplishment, and yet whose legacy is measured not in that accomplishment but rather in the love his family, friends, colleagues, and students have for him. Dr. Burns' most enduring traits are eternal—those of humility, love, and friendship. He has influenced so many lives over the years with his genuine humility and homespun affability that it is truly a challenge to sum up his life and accomplishments in a simple, brief preface. Instead, we have decided to relate a couple of anecdotes that are

personal stories for us, but which we hope will resonate with the many, many others that have grown to admire and love Ned Burns the man.

As we have visited with students and alumni of UT-Austin, and also with non-student visitors to the Austin campus, it is remarkable the number of stories about Ned Burns that we hear with a constant theme—“it was Ned Burns that gave me my first tour of Ferguson Lab.” Bruce’s is a similar story.

In August 1988, Bruce and his wife Candi were faced a very difficult decision—whether or not to move to Austin so that he could enter the Ph.D. program in Structures at UT-Austin. He and Candi visited Austin for a day about two weeks before school started so that he could enroll, and also have a “look around” to see if he thought this was the correct choice for careers. As he wandered up to the 4th floor of Cockerel Hall (ECJ) for advising, he was introduced to Ned Burns, who promptly offered to drive him out to the Balcones Research Campus for a tour of Ferguson Lab. Of course he agreed, curious to see what was inside that magical building. In the ten-mile-or-so drive up the MOPAC, he learned about the structural engineering program at UT—but he also learned that Ned Burns had grown up in Texarkana, Texas, the youngest son in a large family whose father was a school teacher and administrator. He learned how Dr. Burns had met his wife Martha while he waited tables at the Scottish Rite residence hall in the early 1950s. He learned about Phil Ferguson and what an influence he had been on Ned’s life and education. He learned about how the structural engineering faculty worked together on so many projects. He learned about how Dr. Burns’ son Michael was enrolled at Rice University, where Bruce himself had gone to school. He learned about the projects that Dr. Burns was working on. He learned about the Burns’ two daughters, Katherine and Stephanie, where they were in school and what they were studying.

Through that first extended conversation—ostensibly about Ferguson Lab and the Structures program at UT-Austin, Bruce found a warm and engaging man whom he would come to admire even more as time went on. Dr. Burns constantly made connections with Bruce; his conversation about his parents and family history rung true as Bruce thought about his own parents and family. His anecdotes about his childhood linked to Bruce’s own memories about childhood. He waited tables in college to earn spending money as did Bruce. Both their families were rooted in rural southwestern Arkansas or southeastern Oklahoma. But more than that, the conversation was free flowing, and earnest without pretension. Dr. Burns wanted to know about Bruce’s family, about Candi and about her parents. Do you have children? Where is your wife from? How did you meet? From the very first conversation, it was clear to Bruce that Dr. Burns cared about the person more than anything else.

Shawn’s story fittingly evolves from a conversation that he had with Dr. Burns at the ACI Convention in San Diego, in the spring of 2000. Eighteen months after completing his doctorate at UT-Austin under Ned’s supervision, Shawn was a young faculty member at Villanova facing all of the standard challenges and pressures that young faculty face—developing course notes, laboratory facilities, research programs, and so on. As he always did with former students, Dr. Burns was inquiring as to how things were going. Shawn

explained that things were going well, and then started to tell Ned about a new project that he was involved in with one of his courses.

Shawn and a colleague had just taken a group of students to Honduras over Spring Break, to work on the construction of a reinforced concrete cross and masonry building structure that the students had been designing in class as their senior design project. The work was being done for Amigos de Jesus—a home for abused and abandoned boys in rural Honduras. As Shawn explained the project, Dr. Burns listened intently, asked questions, and, of course, became genuinely engaged in the conversation. As the conversation ended, Dr. Burns told Shawn that he was proud of his involvement in such a unique project where the students could exercise their technical academic abilities in a way that helps others. He urged Shawn to continue development of the project and even told numerous colleagues and acquaintances about Shawn's project. Soon enough, Shawn was being approached by others asking for information about the course—all because of the belief that Dr. Burns has in this type of technical service work, and his pride in what his former student was doing.

Since that first conversation, Dr. Burns has maintained a strong interest in "The Honduras Project." When he and Shawn talk about Shawn's career at Villanova, it is invariably the first thing that Dr. Burns asks about. Shawn has come to realize that Dr. Burns is still teaching. His interest in the Honduras project is in part Dr. Burns' way of characterizing the relative importance of different aspects of life. He believes in the notion that the most meaningful technical work is that which helps others or meet a societal need. As every former student of Dr. Burns can attest, he encourages all of his students to become engineers who use their technical abilities to "plant trees that they themselves will never sit under."

Somehow we know others' experiences are similar to ours. Perhaps it was the day you met Ned Burns, or perhaps it was years later during a conversation or some other encounter when you realized the depth of character and the truly generous nature of Ned Burns. Regardless, Dr. Ned H. Burns has made a lasting impression on many of us, whether colleague, friend, or student. One final word regarding an observation about human nature: there is an expression for it—whether or not a particular person "tends to grow on you." We are not sure whether the expression is a southern expression or not, but it is meant as an endearing expression of love and friendship that describes a person that becomes more likeable as one spends time around them. Well, we attest to all that Ned Burns is definitely one person that "tends to grow on you."

On behalf of Committee 423, we are pleased to offer this symposium—a celebration of the development of prestressed concrete over the last half-century—as a tribute to a man who played a significant role in that development and, in doing so, has managed to influence so many lives.

Bruce W. Russell, Chair – Joint ACI/ASCE Committee 423 on Prestressed Concrete
Shawn P. Gross, Secretary – Joint ACI/ASCE Committee 423 on Prestressed Concrete
November 2005

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Contributions of Gustave Magnel to the Development of Prestressed Concrete

by L.R. Taerwe

Synopsis: In the early 1940's Prof. G. Magnel performed extensive research programmes on real scale prestressed concrete beams at Ghent University (Belgium) in order to elaborate design methods for this new material. He also developed his own anchorage system which was used until the mid 60's in Belgium. He gave many lectures in several countries in which he explained in a simple way the principles of prestressed concrete. He was also instrumental in the design of the first prestressed concrete bridge in the USA, the Walnut Lane Bridge in Philadelphia and he was the author of the first English textbook on prestressed concrete. He designed one of the first PC railway bridges in Europe and the first statically indeterminate PC bridge in the world. In the 1950's many engineers from abroad spent some time in Magnel's lab in Ghent to perform research and to get acquainted with practical realizations.

Keywords: history; Magnel; prestressed concrete

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Luc R. Taerwe, FACI, graduated as a civil engineer at Ghent University (Ghent, Belgium) where he also obtained his PhD degree (1985). He is the present director of the Magnel Laboratory for Concrete Research and a full professor of concrete structures at Ghent University. He is a member or chairman of several international technical committees (fib, ACI, IABSE, ...) dealing with concrete or concrete related topics. He is a recipient of the Robert l'Hermite Award (RILEM) and the IABSE prize.

THE "REINFORCED CONCRETE" PERIOD

Gustave Magnel (Fig. 1) was born in 1889 and graduated as civil engineer at Ghent University in 1912. From 1914 until 1919 he was employed by a London contractor and in 1919 he started his career at Ghent University. Due to his stay in London, he was not only fluent in French and Dutch (Flemish) but he was also very fluent in English which would turn out to be extremely useful for his later contacts in North-America. In those days, French was the main language used by engineers in Belgium and also a common language in international contacts within Europe.

In 1923 he published his first book "Pratique du calcul du béton armé" on the design of reinforced concrete. In the same year the Belgian Standards Institute published the first design guidelines for reinforced concrete structures, Magnel being the main contributor. One of his first technical papers dealt with the influence of column stiffness on the stresses in continuous reinforced concrete beams.

For Magnel it became clear that for the further development of reinforced concrete it was necessary to perform research, in other words, he needed a laboratory. After many political and financial difficulties he succeeded in founding the "Laboratory for Reinforced Concrete" in 1926, which was located in the basement of a former hotel. In this lab, Magnel had at his disposal a 300 kN universal testing machine and a 3000 kN compression testing machine. About the efforts he has to made to realise his laboratory and keep it operational he wrote the following : *"The ultra-rapid evolution of technology, forces university institutes to adapt themselves continuously to the actual requirements at the risk of failing in their task. This adaptation can not happen on the initiative of the university management which, by definition, is not competent for it and, moreover, rather looks for savings than for new expenditures. Hence, it is the task of the professors to do the impossible to keep their teaching and research at the required level."* He continued by stating the following : *"It not only goes about having a laboratory : the question is to keep it operational, which requires additional funding. We obtain an extra income from testing we perform for contractors, companies and public authorities, ..."*

In 1937 the laboratory moved to a new building of the engineering faculty where much more space was available and some new testing machines were installed. By 1940, it had become the most advanced and sophisticated research and testing laboratory for reinforced concrete in the world. Magnel had little use for tests on small-scale models and in 1950 a special testing floor was installed, thus enhancing the facilities for loading tests on real scale reinforced and prestressed concrete elements. In 1975 the laboratory moved to a campus at the outskirts of Ghent where it is still located^{1,2}. In the 1990's the

name was modified into "Magnet Laboratory for Concrete Research", indicating that research on both material and structural aspects is performed.

EARLY CONTRIBUTIONS TO THE DEVELOPMENT OF PRESTRESSED CONCRETE

The first mentioning by Magnel of the principles of pretensioned concrete and post-tensioning by external cables was in 1940. These techniques were already used abroad and Magnel tried to convince Belgian companies to apply it as well.

During the second World War, Magnel was not allowed to teach. However, the Germans still allowed him to remain director of the lab he founded. During the secluded years at the laboratory, Magnel had the opportunity to conduct full-scale research on prestressed concrete girders. He also investigated on the phenomena of creep of high-strength steel wires and creep and shrinkage of concrete. During the war period, it was impossible for him to obtain the prestressing system developed by Freyssinet in France. Hence Magnel developed himself a post-tensioning system which became known as the "Belgian" or "Magnel-Blaton" system (Fig. 2). The anchorages of this system consist of several so-called "sandwich plates", arranged parallel to each other, and in contact with a cast-steel bearing plate. Each locking plate is provided with four wedge-shaped grooves in each of which two wires are secured with a steel wedge. In this way the stress in the different wires (typically $\varnothing 5$ mm) of one tendon is more uniform than in the case all the wires are stressed at once. Moreover, a fairly small jack could be used for stressing the wires (Fig. 3). The cable is placed in a sheet-metal sheath, or holes are formed in the concrete to permit the cable to be passed through the beam after concrete has hardened. Over the full length of the tendon, vertical and horizontal spacers were provided at regular distances which assured that the relative position of the wires remained the same along the tendon. Due to this arrangement there was a free space around each wire which allowed a good cover by the injection grout which is essential for protection against corrosion.

The Blaton-Magnel post-tensioning system was used in almost all prestressed concrete bridges in Belgium until the early 1960's. In these years it went out of use because it turned out to be quite laborious and strands were introduced to provide higher capacity tendons.

In 1946 he published his design method for statically determinate beams. He formulated the following four stress conditions under service loads in the critical section :

1. tensile stress at top fibre under initial prestressing and dead weight smaller than allowable tensile stress.
2. compressive stress at top fibre under prestressing and full load smaller than allowable compressive stress.
3. compressive stress at bottom fibre under initial prestressing and dead weight smaller than allowable compressive stress.
4. tensile stress under long-term prestressing and full load smaller than allowable tensile stress.

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These inequalities were drawn as straight lines in a diagram with axes $1/P_i$ (P_i : initial prestressing force) and e (eccentricity) and resulting in a kern showing admissible combinations of P_i and e (Fig. 4). In principle, the eccentricity giving the smallest value of P_i was chosen.

For shear design he took into account the beneficial effect of the prestressing force on the total shear force. He then looked for the section and the fibre where the principal tensile stress was maximum and compared this stress with an allowable value.

For the design of the end-blocks he proposed to calculate the shear force and bending moment in horizontal sections, which is the so-called deep beam analogy. The resulting shear and normal stresses were combined with the stress components from other sources to calculate the principal tensile stress.

In 1951 Magnel stated the following³ : *"In my opinion, for each beam two calculations have to be made : the first based on stresses using the elastic theory, the other on ultimate load. However, it seems to be impossible at present to make this latter calculation accurately because all known methods require the use of coefficients, the value of which we really ignore. This is mainly true when the failure occurs by crushing of the concrete. I recommend the design based on stresses as the fundamental one, but as it does not always give the same factor of safety against ultimate failure, an attempt must be made in each case to check whether this factor of safety is sufficiently high."*

In 1946 he had already tested a partially prestressed beam for which the cracking load was lower than the full service load as opposed to the original concept of prestressed concrete in which no longitudinal tensile stresses were allowed under service conditions. Although Freyssinet was heavily opposed to the use of partially prestressed concrete, Magnel realized that it could offer some advantages.

In 1947 he developed a practical solution for the case of statically indeterminate post-tensioned beams. He introduced the concept of secondary bending moments $M_{P,sec}$ generated by the prestressing force P , and defined the equivalent eccentricity as

$$e_{eq} = e + M_{P,sec}/P \quad (1)$$

In this way, he could use a similar diagram $1/P_i$, e_{eq} as for statically determinate beams. The relationships between the actual (geometric) eccentricities and the equivalent ones were calculated on the basis of expressions for the secondary moments.

As he had gathered sufficient theoretical knowledge and practical experience about PC, he wrote his first book on the subject⁴. It was first published in French in 1948 and was soon translated in English and Spanish.

FIRST PROJECTS IN BELGIUM

In the railway bridge over the "Rue du Miroir" in the Brussels' north-south train connection, two of the six bridge decks were realized in prestressed concrete (Fig. 5). For a span of 20 m a total depth of 1.15 m proved to be sufficient while a solution in reinforced concrete would have required an increase in slab depth by 0.7 m. This bridge was considered a pilot project and the related research project was partly sponsored by the Belgian Fund for Scientific Research. Hence, in 1944 Belgium was one of the first countries with a prestressed concrete railway bridge. On this project Magnel concluded the following : *"In our opinion, prestressed concrete is the building material of the future. Over 10 years, very few bridges will still be built in reinforced concrete because everybody will be convinced of the advantages of prestressing. The realization of the pilot project in the Rue du Miroir will have been the catalyst of this evolution and all who were involved in it can be proud of the results obtained."*

The first prestressed road bridges in Belgium were built in Zammel (start in 1944 ; 12 m span) and in Eeklo (1945-1946 ; 20 m span).

In 1947-1948, a new textile factory was built for the UCO company (Union Cotonnière) in Ghent which had, in those days, the largest roof structure worldwide in prestressed concrete, covering a surface of about 35000 m² and which is still intact (Fig. 6). One hundred primary beams with a span of 20.5 m and 600 secondary beams with a span of 13.7 m were necessary. All these beams were precast at the site at a rate of 3 primary beams and 18 secondary beams per week which required a perfectly organised casting yard. Magnel writes about this achievement : *"During the last 3 to 4 months, this project attracts numerous architects, engineers and contractors both from Belgium and from abroad. They want to qualify themselves in the field of prestressed concrete, firstly in our lab and secondly at the building site"*.

In the same period a hangar for planes at Melsbroek, the former Brussels airport, was erected. The roof was supported by 17 post-tensioned beams having a total depth of 2.9 m and a mass of 300 tons (Fig. 7). Similarly as in the previous project, the beams were cast on the ground and, after post-tensioning, they were lifted into their final position.

In 1949, the famous Sclayn bridge over the river Meuse was constructed (Fig. 8). This was the first continuous prestressed concrete bridge in the world (Figs. 9 and 10). With two spans of about 63 m each, the bridge was also the longest prestressed bridge in the world. Due to the variable depth of the girder, the external cable profile was almost straight except for the kink at the central support. At that section, the secondary moment due to prestressing was equal to about 68 % of the local bending moment due to dead weight.

THE WALNUT LANE BRIDGE

In 1946, Magnel visited for the first time the United States of America as an "advanced fellow" of the Belgian-American Educational Foundation, founded by Herbert Hoover in

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1920. The trip was organized by the late Charles C. Zollman, a former student of Professor Magnel at Ghent University⁵. Later he became Magnel's unofficial representative in the United States, responsible for the detailed arrangements of Magnel's several trips to this continent. Mr. Zollman's early consulting services for the design and construction of pretensioning plants throughout the United States, his activities in the field of precast concrete as well as his many contributions to the PCI, have identified him as a pioneer of this industry in North America. During his first visit to the United States, Magnel lectured on prestressed concrete at several places, a subject almost unknown at that time in that country. Magnel had the rare gift to explain complex theories and difficult problems in a simple way and thus captivated large audiences.

Two significant effects occurred during Magnel's first visit to America which had a direct bearing on the development of prestressed concrete in America and which culminated in the realization of Philadelphia's Walnut Lane Bridge, the first prestressed concrete bridge in the USA (Fig. 11). The first event was the fact that Magnel was introduced to the Preload Corporation of New York, which eventually became a sub-contractor for the construction of the Walnut Lane Bridge girders. The second event was the fact that Magnel asked Zollman to translate the French manuscript of his book on prestressed concrete into English. After a lot of efforts and difficulties the book was published in London in 1948. The 6000 copies of the first edition were promptly sold out. Eight thousand copies of the second revised and expanded edition were published in 1950 and a third further edition was published in early 1954. During those early years, Magnel's book was the practical tool to which engineering students and practicing engineers referred to for the design and analysis of prestressed concrete structures. The impact of this treatise, as well as many of Magnel's other publications, had on the prestressed concrete industry is indeed significant. In the early 1950's, T.Y. Lin spent one year in Magnel Laboratory and after his return to the United States he published his book on "Design of Prestressed Concrete Structures" (1955).

In the late 1940's Ch. Zollman, who had joined the Preload Corporation in the meantime, could convince the Bureau of Engineering of the City of Philadelphia to realize the superstructure of the Walnut Lane Bridge in prestressed concrete on the basis of a proposal elaborated by Magnel. The Preload Corporation was awarded the sub-contract to fabricate the girders in 1949. In October 1949 a loading test was performed on a 49 m long and 2 m deep test girder, identical to the girders forming the center span of the bridge (Fig. 12). This test demonstration attracted some 300 engineers from seventeen states and five countries who stood in the rain for the entire day to witness the event. The successful testing to destruction at the job site, far away from the comforts of a laboratory, was a significant achievement which instilled public confidence in prestressed concrete. Ch. Zollman formulated it as follows : *"No single event was more instrumental in launching the prestressed and precast concrete industry in North-America than the construction of the Walnut Lane Bridge in Philadelphia in 1950. More than anything else however, it was the charisma, the dynamism and engineering talent displayed by the man who designed the Walnut Lane Bridge, namely Prof. Gustave Magnel of Belgium, that gave the impetus necessary for the acceptance and development of prestressed concrete in the United States."*

Prior and during the execution of the bridge, some problems needed to be solved because Magnel required a "zero slump" concrete. According to American practice this was not possible to realize but Magnel had to approve all execution details. Finally, a practical solution was found but several girders showed honeycombs and other imperfections⁶ (Figs. 13 and 14). The controversy had gone far enough to be published in the influential "Engineering News Record" with the headline⁷ : *"Americans make soup, not concrete, says Belgian professor"*.

In October 1950, Prof. Magnel was awarded the Frank P. Brown Medal from the Franklin Institute in Philadelphia for his exceptional contributions to the development of prestressed concrete.

During the service life of the Walnut Lane Memorial Bridge, some of its girders underwent major repairs and finally it was decided to replace the entire superstructure. Site preparations to remove the existing girders began in 1989. The reconstruction of the bridge and the realignment of its approaches in 1990 stirred up nearly as much interest and curiosity in the engineering and construction community as did the original structure in 1949. The new girders, based on a modified hybrid standard AASHTO Type V girder, were all manufactured in a PCI-certified plant instead of the girders being constructed and post-tensioned on site.

THE SEQUEL

In the early 1950's several famous American researchers visited Magnel and his Laboratory, among which T.Y. Lin, David P. Billington (Princeton University) and Robert N. Bruce (Tulane University, New Orleans).

Together with other European pioneers of prestressed concrete, Magnel founded in 1952 the "Fédération internationale de la Précontrainte", abbreviated as FIP, which became a successful international technical organization. In 1996 it merged with CEB (Comité Euro-International du Béton) into fib (International Federation for Structural Concrete).

Magnel not only authored more than 180 technical papers but also published an impressive series of books on structural analysis and on the design of reinforced and prestressed concrete structures. In all these text-books practical design methods were given which use was facilitated by numerous tables and graphs.

During his last years, Magnel devoted a lot of energy to the preliminary design of a high TV-tower, which was planned for the World Expo 1958 in Brussels. The planned tower in reinforced concrete would have had a diameter of 100 m at its base and a height of 500 m. On top of the concrete part came a steel mast with a height of 135 mm. In those days this would really have been a world wide attraction. However, there was a lot of technical and political controversy about this project and finally it was decided not to build it.

Gustave Magnel passed away quite suddenly on July 5, 1955. This sudden loss was received with great sadness in Belgium as well as abroad.

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In October 1956, an academic session was organized in Ghent for the commemoration of Gustave Magnel, where also several of his former colleagues and friends from abroad were present. At that occasion Prof. R. Evans from Leeds University mentioned the following : "... *His concrete laboratory was recognized as one of the best in the world. Hundreds of members of staff and research workers from a large number of universities have had the pleasure and privilege of visiting this excellent laboratory. Magnel always warmly welcomed at his laboratory those who wished to improve their knowledge. His gift of friendly intercourse enriched us all by their genial and mellow qualities. Although he often had strong views on technical questions, he was by nature so generous that it was a pleasure even to disagree with him.*"

In order to continue the commemoration of Prof. Magnel's exceptional achievements at long term, the General Association of Engineers graduated from Ghent University (AIG), bestows the "Golden Medal Gustave Magnel" every fifth year on the designer of a structure which is deemed to be an important and remarkable application of reinforced or prestressed concrete. The first ten recipients are : N. Esquillan (1959), P. Blokland (1963), F. Leonhardt (1968), U. Finsterwalder (1973), R. De Keyser (1979), H. Wittfoht (1984), R. Greisch (1988), O. Olsen (1994), M. Virlogeux (1990) and J. Schlaich (2004).

CONCLUSIONS

From the previous overview it is clear that Prof. Gustave Magnel was an exceptional personality both from an academic and a human point of view. The following achievements can be pointed out :

- Contributions to practical design methods for reinforced concrete.
- Development of his own prestressing system.
- Development of design methods for prestressed concrete and authorship of the first English text book on the subject.
- Involvement in the design and realization of the first continuous prestressed concrete bridge worldwide.
- Contribution to the realization of the Walnut Lane Memorial Bridge in Philadelphia, the first prestressed concrete bridge in the USA.

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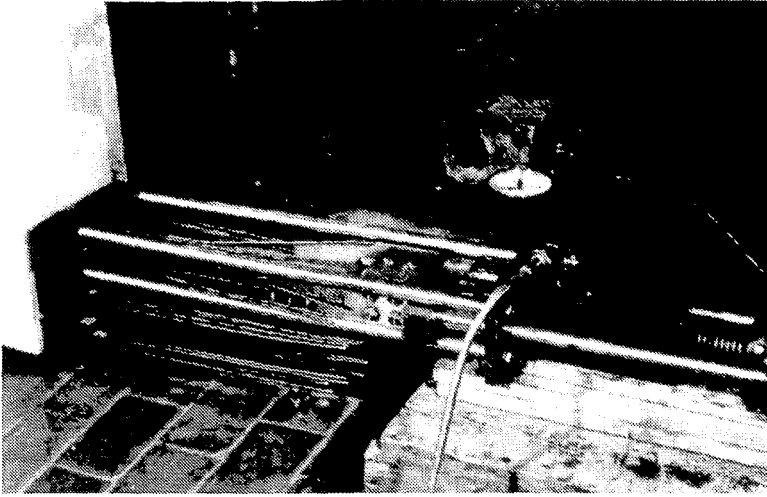


Figure 3 – Jack for the Blaton-Magnel system

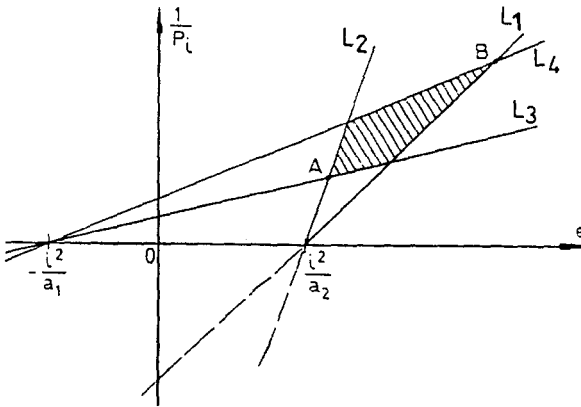


Figure 4 – Allowable kern for combinations of $1/P_i$ and e

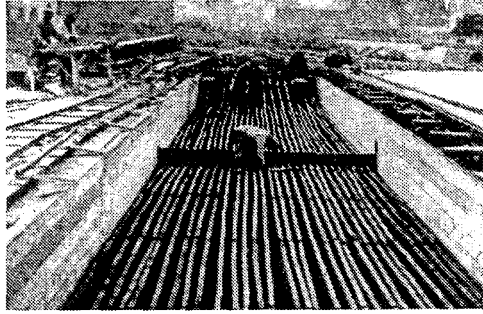


Figure 5 – Railway bridge over the “Rue du Miroir” in Brussels (1943-1944)

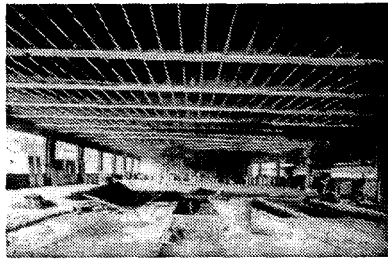


Figure 6 – Textile factory with post-tensioned roof beams (1947-1948)

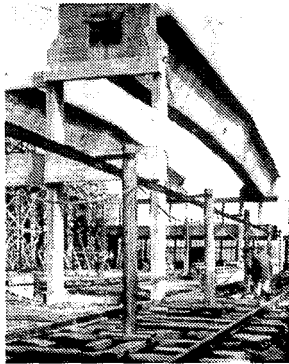


Figure 7 – Heavy beams for plane hangar at Melsbroek airport

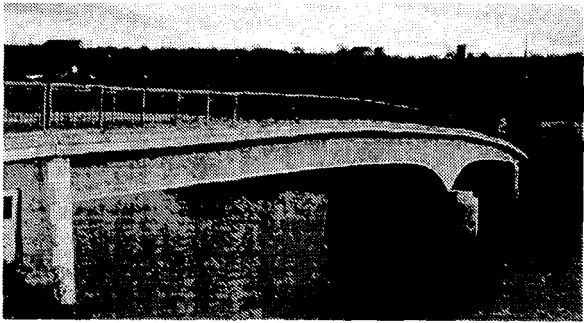


Figure 8 – Bridge at Sclayn over the river Meuse

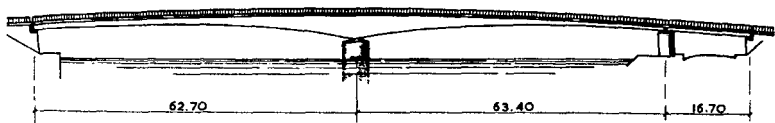


Figure 9 – Bridge at Sclayn : lateral view

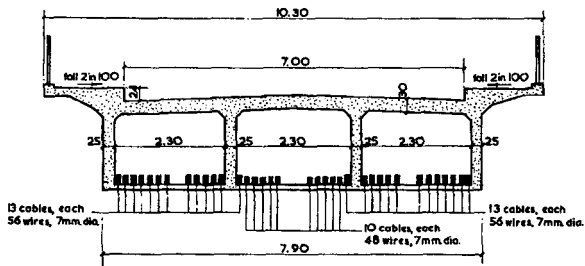


Figure 10 – Bridge at Sclayn : cross section



Figure 11 – Walnut Lane Bridge in Philadelphia



Figure 12 – Loading test on girder for the Walnut Lane Bridge



Figure 13 – Honeycombs in the first girder cast in 1949

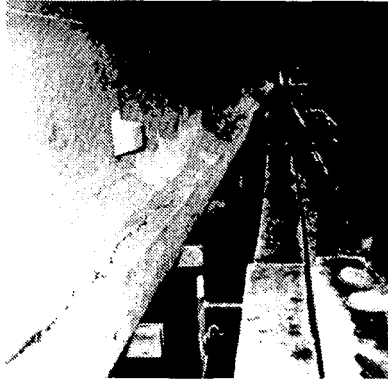


Figure 14 – Longitudinal crack on the outer sloping face of the bottom flange
(south fascia girder)

Early Applications of Prestressed Concrete in the United Kingdom

by C. Burgoyne

Synopsis: The initial impetus to the application of prestressed concrete in the United Kingdom was heavily driven by the conditions imposed by the Second World War. Refugees from Germany, particularly Mautner and Abeles, brought skills and knowledge of tests carried out in France and Germany. The need to provide emergency structures, both for military purposes and to meet civilian needs, together with shortages of many materials, especially steel, led to the construction of beams on a scale, and at a speed, which would not have taken place in more normal times. The paper covers developments in the UK from the outbreak of the war in 1939 up to the early 1950s, when more normal times returned. This period of development is still not properly documented because security conditions prevented the publication of full details of the applications.

Keywords: history; prestressed concrete; United Kingdom

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INTRODUCTION

Prestressed Concrete was not developed in Britain, but several early applications took place there. The Second World War had a major effect since it significantly affected both the need for structural elements and the supply of materials.

Freyssinet's used jacking at the crown of arches at Rairéals-sur-Besbre (1911), Veurdre (1912) and Boutiron (1913 – Figure 1) to overcome the effects of concrete shrinkage and creep¹, and he conducted laboratory experiments which eventually led to his influential patent in 1928². Glanville's more theoretical work on creep at the Building Research Station in England was taking place at the same time³, but it was undoubtedly Freyssinet's work that led directly to prestressed concrete. He recognised that high-strength concrete and high steel pre-strains were needed to leave some prestress after creep had taken place.

The first publication drawing the attention of British engineers to prestressed concrete was a paper by Gueritte in 1936, read before the Institution of Structural Engineers; this was a translation of a paper by Freyssinet, who attended the meeting⁴. Gueritte had, as early as 1931, read a paper before the British Section of the Société des Ingénieurs Civils de France, describing the views of Freyssinet⁵; this was only one year after Freyssinet had extended his patent for the use of prestressed concrete. The 1931 paper was, however, more concerned with the bridge at Plougastel, near Brest, and the novel centring system used there. It refers to the properties of concrete lying somewhere between those of a solid and a liquid (an implicit reference to viscoelasticity), but gives few details. It also talks of the benefits of providing confining reinforcement to enhance the strength of the section.

The company of L. G. Mouchel and Partners, who had built up a pre-eminent role in reinforced concrete as holders of the U.K. licences, set up the Prestressed Concrete Company as early as 1937. The company does not appear to have become fully active until the arrival in the UK of Dr. Karl Mautner in the summer of 1939. Mautner had been a director of Wayss & Freitag in the 1930s, and was also a professor at Aachen. He was of Jewish descent, but despite holding the Iron Cross as a result of his distinguished service in WWI, he was rounded up with other Jewish professionals and placed in Buchenwald concentration camp in 1938. At that time, however, it was possible to buy oneself out of the camps and with the help of the Mouchel Company in England, and probably also of the British Secret Services, he came to England. He brought with him details of Freyssinet's work, with which, as licensee, Wayss and Freitag had been actively involved⁶.

Gueritte published two further papers in the early 1940s. The first⁷, in July 1940, describes the mass-production of precast, pretensioned beams; it also describes the design of emergency bridge beams and the design of a 3-span post-tensioned river bridge with a main span of 48 m, the central 15 m of which were formed of a simply-supported span. There was also a technical appendix written by Mautner. The second paper, published in 1941⁸, gave extensive details of a test carried out at Southall on a beam 8.8 m long (Figure 2), and also described the test carried out about 5 years before, in Germany, on a longer beam designed by Freyssinet and tested by Mautner. The various developments sprang from this work.

In this paper locations are given using the Ordnance Survey Grid Coordinate system⁹, which consists of two letters and 6 numbers, sufficient to define any location to within 100m. These coordinates, when entered into UK-based web mapping systems¹⁰, will produce detailed maps of each location, at a variety of scales.

WAR-TIME CONSTRUCTION

Monkton Farleigh Mine. The limestone mines at Monkton Farleigh in Wiltshire (ST799656) had been worked in the 18th and 19th centuries to extract a seam of high quality freestone that was used to construct the city of Bath. The seam was about 5 m thick and typically 25 – 30 m below the surface. It had been excavated using the pillar and stall method, leaving quite sizable columns of stone to support the overlying lower-quality limestone that was not extracted (Figure 3). This mine, and others in the vicinity, were used as bomb-proof bunkers to store ammunition and other ordnance before it was required¹¹. They covered some 80 hectares and were capable of storing about 350,000 tonnes of bombs. Monkton Farleigh mine was connected to the main Great Western Railway by means of a narrow-gauge railway tunnel and also by an aerial ropeway.

The original pillars left by the miners were irregular, and not suited to mechanical handling, so it was decided to replace the pillars by regularly-spaced walls, 5 m apart, and to use prestressed concrete beams at 1.5 m centres. Mr Allan of the Ministry of Public Buildings and Works, and Lt-Col Withers of the Royal Engineers, decided in 1939 to investigate the use of prestressed concrete for these beams, which were designed in consultation with Mautner and successfully tested¹². They were designed for a central point load of 81.5 kN applied at the centre of the span, and were clearly intended to restrain loose blocks of stone falling from the roof rather than supporting the whole of the overburden, so they do not appear to have been loaded initially. Access to the mine was by inclined adits. Figure 4, which was not taken specifically to include the beams, shows two such girders. They were supported at their ends by steel rods hanging from brackets let into the walls; in the photograph these have been sprayed with concrete, presumably as corrosion or fire protection.

The scheme went ahead, with the intention that every third wall would be built, after which the intervening pillars would be removed and the intermediate walls completed. However, the demolition of the pillars took place much more quickly than the building of the walls, with the result that large areas of the ceiling were left unsupported and some of

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the walls that had been completed were overloaded¹³. A collapse occurred and the whole rebuilding scheme was cancelled, with the result that only a limited number of prestressed beams were installed. Nevertheless, this appears to be the first use of prestressed concrete in the UK.

The beams are described in Gueritte's paper in 1940⁷; although he does not mention the mine by name it is clear that these are the beams to which he refers. The paper also gives details of the anchorage blocks used in the stressing beds (Figure 5). With plans to fabricate such a large number of beams in a very short period of time, long-line fabrication was adopted. Nine parallel prestressing beds were made, 151 m long, in each of which 28 beams could be produced at the same time. The beams were complex in shape; the drawings show them with rectangular cross-section at the ends but I-beam section in the middle, with a web whose thickness varied along the length. 282 such forms would have been required if all beds were in use simultaneously. Shear links were provided and individual link spacings were specified, which today would be regarded as impractical, although it shows the over-riding importance attached to the optimisation of the steel. The tendons were stressed to about 1140 MPa so extensions of nearly a metre had to be accommodated at the jacking point. This was done by stressing pairs of wires using a yoke, with packing being installed once the desired extension had been reached. Once the concrete had cured sufficiently, the jacks were reinstalled, the packing removed, and the prestress released. If all 3000 beams had been built, each mould would have been used 12 times, and allowing for transfer of prestress at an age of seven days, with another week in between for setting up the reinforcement and concreting, it would have taken some 6 months of flat-out operation to complete the order.

There was relatively little to see on the surface, with a view to avoiding the attentions of the Luftwaffe, but the site was bombed in August 1940; it is thought that the bombers mistook the stressing bed for the (much longer) runway on a nearby airfield which was their intended target. Figure 6 was taken by the RAF to check the site camouflage; it was deemed to be unsatisfactory.

The mine is no longer used to store ammunition, but some parts have been taken over for commercial secure storage of documents and computer media. As a result, large parts are inaccessible and none is open to the public. Some of the beams are still in place, although their present condition is unknown. Grote gives a sketch of the present layout of the beams⁶.

Railway Ties (Sleepers in UK parlance). Prestressed concrete railway sleepers were introduced in 1942¹⁴. There had previously been experiments with reinforced concrete sleepers, as early as 1917 in Ireland, with others on the LNER main line in 1928, but these were generally unsatisfactory as the reinforced concrete crumbled when subject to frequent heavy loads¹⁵. Wartime difficulties in obtaining suitable hardwood for the traditional timber sleepers led to further experiments in 1941 with reinforced concrete¹⁶, and some were put onto a branch line near Derby. The tests were inconclusive, so the next year 100 of the sleepers were placed on the main LMS line near Watford; they survived for 10 days. At the same time, development work was under way on prestressed

concrete sleepers, designed by Mautner for production on an experimental long-line stressing bed at the Royal Signals Research Establishment (RSRE) at Malvern. The first of these sleepers was used in a trial in 1942 and they were so successful that all work ceased on reinforced concrete apart from occasional use in sidings. A purpose-built factory was constructed by Dowsett at Tallington in 1943 and continues in production to this day (Figure 7)¹⁷. It has been estimated that after 50 years of production there were some 35 million prestressed, pretensioned, monoblock sleepers in use in the UK alone¹⁴.

The sleepers are designed for point loads applied by the rail, to be resisted by upward pressures from the ballast (Figure 8). If the ballast is in good condition, support is concentrated under the rails, but after settlement the ground support can be much more uniformly distributed. The sleepers are normally in hogging bending between the rails, and sagging bending under the rails; the top profile is altered so that the tendons remain straight but are in the appropriate position to resist the different moments. No other reinforcement is provided in the sleepers apart from a fixing to attach the rails¹⁴.

Emergency Bridge Beams. During the early part of WWII there was a considerable need for bridge beams for emergency repair. Many of these beams were made of steel, but it is known that a number of prestressed concrete beams were also made. It is not known how many beams were made nor, to a large extent, is it known where they were used. Gueritte⁷ describes standard beams designed for spans of 4.6 m, 6.1 m, 9.1 m, 12.2 m and 15.2 m. The beams were to be used side-by-side, with timber decking. In some cases, the beams were to be tied together transversely by prestressed rods, which also served to attach the handrails (Figure 9). It is clear that savings in the amount of steel required were one of the primary advantages seen for these beams; it is also clear that these bridges were expected to be temporary and were seen as a means of restoring communication in the event of bomb damage. One surprising aspect is the preponderance of box beams in the smaller sizes; although they are more likely to be stable when placed, without any need for a transverse tie, the internal shutter must have been difficult to form and wasteful of resources.

In the discussion to a later paper⁸, Chettoe describes the construction method, which is very similar to that used for the Monkton Farleigh beams. He mentions three fabrication yards, using beds between 180 m and 250 m long, each with three or four parallel lines, but he does not give named locations. Presumably these did not include the facility at Monkton Farleigh itself, but it is very likely that they were situated at other Government research establishments, such as RSRE where the sleepers were made. It is clear that a very large number of these beams were probably built, but there is no central record of where most of them were used. A paper published in the Institution of Civil Engineers in 1943¹⁸ refers to two bridges built with these beams; these were clearly intended as permanent installations. Mention is also made of another that was planned.

Bridge over the LMS in Lancashire. This bridge was one of those described in the 1943 paper¹⁸ (Figure 10). It has now been removed, but was located at OS Grid reference SJ595948, where the A49 road crosses the West Coast Main Line in Newton-le-Willows. The bridge was unofficially known as the Bloodystone Bridge since nearby was a

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monument to the murder by a returning crusader of his wife's lover. The bridge was unusual in that the beams were skew to both the road and railway; the girders available from the emergency bridge stock had to fit onto the existing bridge abutments and were not the correct length for the skew span (Figure 11). The bridge was assessed in the early 1990s and a 7 tonne weight limit applied; the original cast-iron parapet beam and the reinforced concrete slab at the side were replaced in 1993. The prestressed girders were replaced in 1997; one of the principal reasons for its removal was the lack of shear reinforcement linking the beams to the top slab.

Bridge in North Yorkshire. The other bridge referred to in the 1943 paper is at Sinderby, where the Great North Road, now the A1, crossed the Ripon to Northallerton Railway¹⁸ (Figure 12). It is at OS Grid Reference SE335811. The road was dualled in the 1950s by adding two further carriageways to the west of the existing road; the old road over the bridge now forms a little-used private access and is not part of the public highway. The railway line has closed, and the void beneath both bridges has been filled-in with earth and concrete, but the bridge deck, including the prestressed beams, remains in position (Figure 13). The degree of support provided by the in-filling must be doubtful, and it certainly prevents both ventilation and inspection. According to Thomas¹⁹, this bridge may have succeeded the LMS bridge above since it is said to have incorporated ties to stop the beams spreading, which had occurred on the other bridge. Despite having similar spans and prestress to the bridge at Newton-le-Willows, and also having no steel linking the beams to the slab, this bridge has never had a weight limit imposed. The long-term future of the bridge is uncertain since the road is soon to be upgraded to motorway standard and the bridge will cease to have any use.

POST-WAR CONSTRUCTION

After the end of World War II, Britain's economy was in a very poor state, with serious shortages of materials. Indeed, food rationing became worse after the end of hostilities, and as much production as possible was diverted for export to earn foreign currency. The back-log of maintenance that had built up meant that there was a heavy demand for steel; one of the principal drivers for the adoption of prestressed concrete was thus the recognition that prestressed concrete structures typically needed only about 25% of the amount of steel for the flexural reinforcement and a slightly reduced need for shear reinforcement because of the axial prestress that was induced.

The stock of emergency beams was used to rebuild bridges. It is claimed that they were so cheap that new construction was unable to compete. No central record exists of where these beams were used, but four locations were mentioned in 1949 in a brief note "An Exhibition of Prestressed Concrete"²⁰; Linford (Hampshire), Bury St Edmunds (Suffolk), Tilemill (Berkshire) and Newport Fronbridge (Pembrokeshire). However, it is probable that a very large number of these beams existed and they would have been too valuable an asset simply to throw away. Detailed locations of these bridges, and any others made with the same beam stock, together with photos and condition reports, are still sought.

Adam Viaduct (1946) near Wigan carries the LMS railway from Wigan to the South West, over the River Douglas, at SD571051²¹. It has four spans of about 8.8 m each, with sixteen I-beams in each span²² (Figures 14 and 15). It was prestressed with the Freyssinet system. The advantages were claimed to be the speed of erection and the fact that ballasted track could be used; the heavier beams meant that the bridge was also less susceptible to vibration. This bridge is still in use and has recently (1999) been listed by English Heritage, a process that recognises its architectural or historical significance, and gives some degree of protection.

Nunn's Bridge, at Fishtoft near Boston in Lincolnshire, was the first application of post-tensioning in the UK, in 1948²³. The bridge has five beams 21.3m long, 1.1m deep below an integral top slab (Figure 16). Each beam has twelve Freyssinet 12-wire draped tendons. The bridge replaced a three-span brick arch built by Rennie which was temporarily retained to support the falsework. The bridge is still in use and shows no sign of rust staining or deterioration of the concrete; the only maintenance undertaken appears to be attention to the handrails. The bridge is located at TF367415.

Masonry Repair (1948). The first application of the Magnel system in the UK was to the strengthening of a church tower at Silverdale near Newcastle-under-Lyme in Staffordshire²⁴ (Figures 17 and 18). The tower was suffering seriously from subsidence caused by coal mining. The badly-cracked masonry was injected with grout to consolidate the brickwork to form "beams" of appropriate shape. A channel was cut into these beams to receive the tendons which were stressed against steel anchorage plates. Subsequently, the chase was filled with concrete to protect the tendons. The intention was that, if any further subsidence occurred, the internal beams would behave as if simply supported and prevent any further cracking of the masonry.

Airport Taxiway (1949). A prestressed concrete taxiway was built at the London Airport at Heathrow^{25, 26}. This was similar to a complete runway slab built by Freyssinet at Orly; the slab was only prestressed transversely, but was made up of a series of 45° triangles (Figure 19). Vertical rollers were inserted in the joints, so as the slab contracted transversely it pushed against end abutments, thus inducing a longitudinal prestress as well. This system neatly overcomes the friction that would arise if direct application of the longitudinal prestress were attempted. The slab was 120' wide by 355' long. At about the same time a prestressed concrete road was constructed at Crawley, but this was prestressed longitudinally, which must have caused significant friction to develop between the slab and the ground²⁷.

Prestressed concrete in buildings (1949). Two notable applications of prestressing to buildings took place in 1949. The first was the fabrication of roof beams for the new Heathcote Factory at Tiverton in Devon²⁸, while the second was a much larger application to a new storage and distribution facility for H.M. Stationery Office at Sighthill in Edinburgh. This was the forerunner of precast, prestressed building construction^{29, 30}. The secondary roof beams were pretensioned in a factory, while the main beams and the secondary beams for the floor were precast on site and post-tensioned before lifting them into position. These beams used the Magnel system, and some of the tendons were curved up at the ends. This building is regarded as significant

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since it took the ideas of precasting and prestressing from the bridge community to the building community.

Partially Prestressed Concrete. Paul Abeles was another refugee who came to England just before WW2. He was a believer in what is now called partially prestressed concrete, where additional untensioned reinforcement was included in the beam. The idea was to increase the ultimate moment capacity in the beam, with the primary effect of the prestressing being to reduce the crack widths but not to prevent their formation. He published a paper³¹ espousing his views in 1940, which was severely criticised by Mautner in the subsequent discussion. The first major application of his techniques is believed to be the reconstruction of railway bridges for the electrification of the LNER railway out of Liverpool Street Station in London. The bridges had to be raised to allow clearance for the overhead wires, without needing to raise the road. These beams were discussed in a paper in 1952³². His systems were openly criticised - there were many who said that rather than combining the advantages of reinforced and prestressed concrete it combined their disadvantages instead. That debate continues to this day!

Conflicting systems. In the years after WWII there were many conflicting prestressing systems. The Freyssinet system, under the guidance of Mautner and later Alan Harris, were already established in the UK and held valid patents, but immediately after the war Prof Magnel of Ghent University was actively publicising his system, and Abeles was proposing the use of partially prestressed concrete. Many other systems were developed; some to avoid the patents held by the early protagonists, but others with genuine improvements³³. It was during this period that today's standard systems were developed using 7-wire strands held by 3-piece wedges.

The history after 1950 is well-documented - *Concrete*, *The Structural Engineer* and the *Proceedings of the Inst. Civil Engineers* all carry many papers relating to innovations or landmark prestressed concrete structures, and there have been a number of papers and reviews giving details of prestressed concrete over the next 50 years^{34,35,36,37,38,39}.

CONCLUSIONS

While it is clear that prestressed concrete would probably have become a successful material anyway, the special circumstances that came together in the United Kingdom between 1938 and 1950 led to the more rapid introduction of the technique. Refugees from Germany brought skills and knowledge with them; pressures to produce a large number of beams very quickly for wartime purposes, combined with shortages of materials, especially steel which was needed for many other purposes, all contributed to the rise of prestressed concrete. Only after the war did questions about patents and commercial exploitation arise.

It is probably unsurprising that wartime security concerns meant that details of the use of prestressed concrete were not published more widely, and other technical achievements in the war, such as Radar, the Spitfire, codebreaking and more visible civil engineering

achievements, such as the Mulberry Harbours, have captured public attention. But the more effective use of concrete by prestressing also played its small part.

ACKNOWLEDGEMENTS

Figures 3, 4 and 6 were provided by Nick McCamley; Figure 11 by St Helens Council; Figures 14 and 15 by wiganworld.co.uk .

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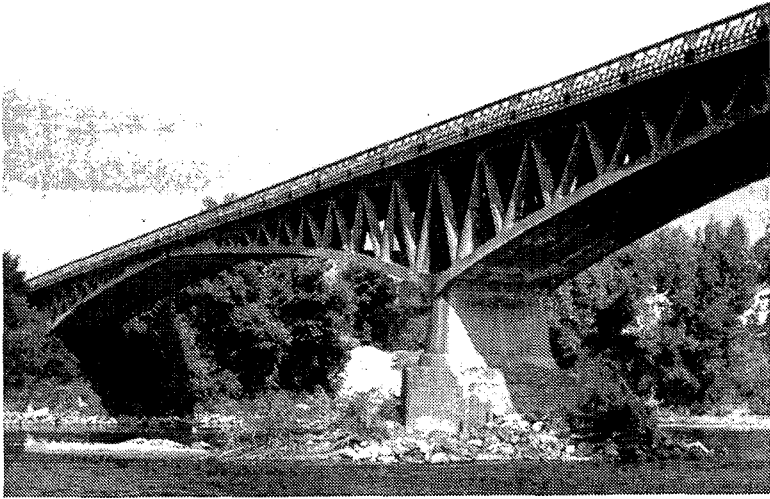


Figure 1 – Boutiron Bridge

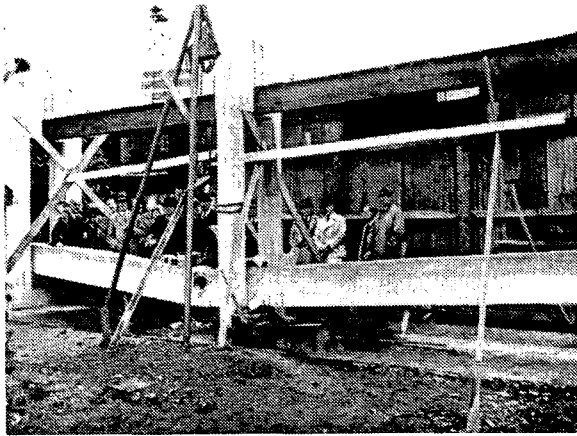


Figure 2 - Southall beam test⁶



Figure 3 - Pillar and stall mining at Monkton Farleigh

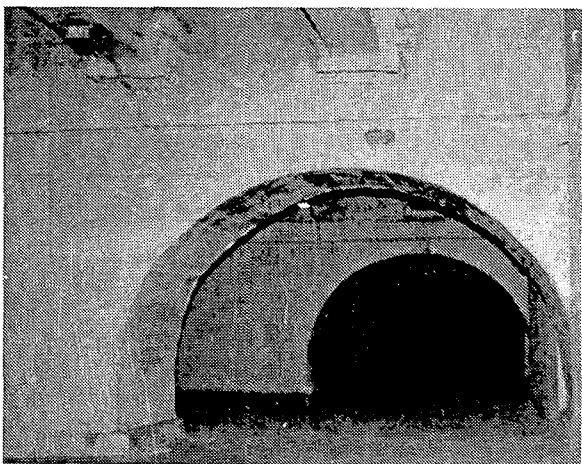


Figure 4 – Two beams in place at Monkton Farleigh

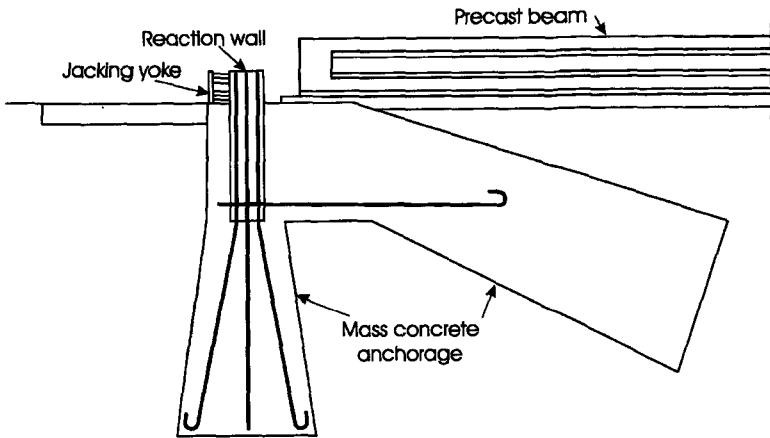


Figure 5 - Anchorage block at Monkton Farleigh stressing bed⁵



Figure 6 - Aerial view of the prestressing bed at Monkton Farleigh (ST797658)



Figure 7 - Original long-line prestressing beds for railway sleepers¹³.

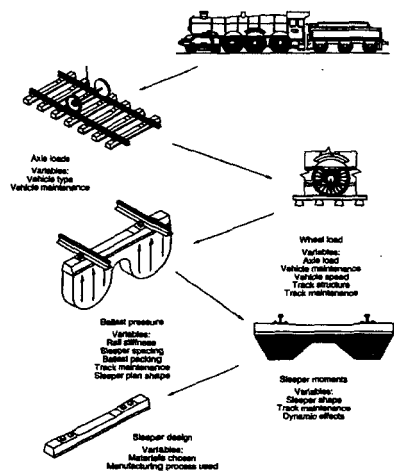


Figure 8 - Sleeper design process¹³

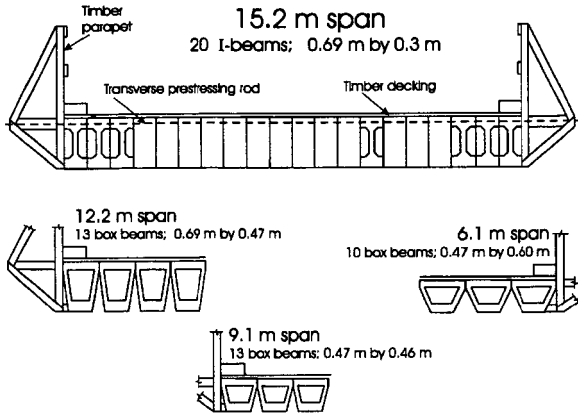


Figure 9 - Emergency bridge cross sections (Redrawn from Reference 7)

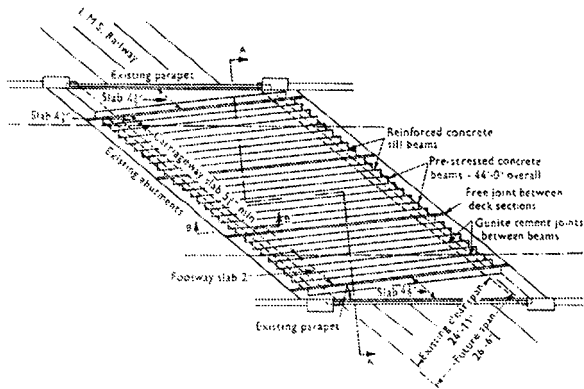


Figure 10 - Plan of Bloodystone Bridge¹⁷

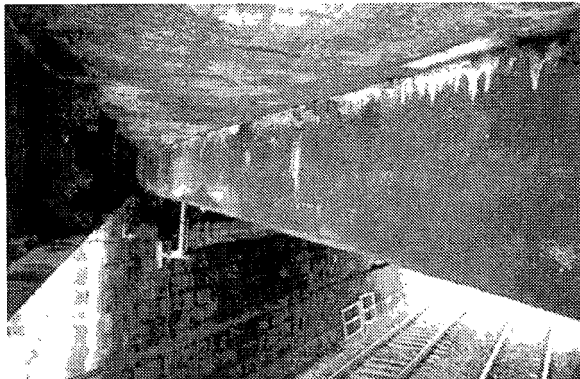


Figure 11 - Underside of Bloodystone Bridge showing cast-iron edge beam and tapering reinforced concrete side slab.

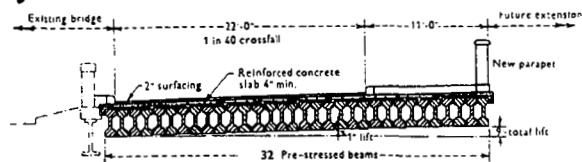


Figure 12 - Cross section of Sinderby Bridge¹⁷

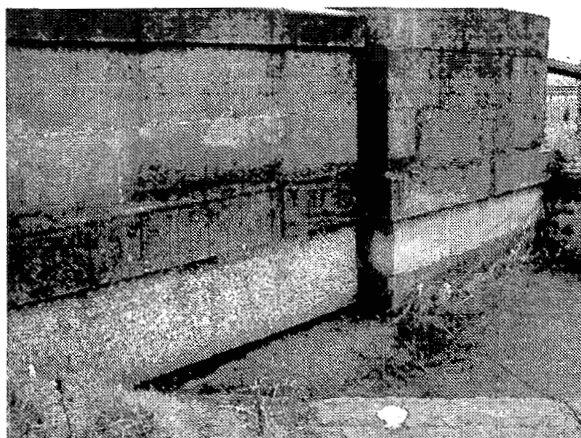


Figure 13 - The only exposed part of the prestressed beams at Sinderby (below parapet)



Figure 14 - Adam Viaduct, Wigan

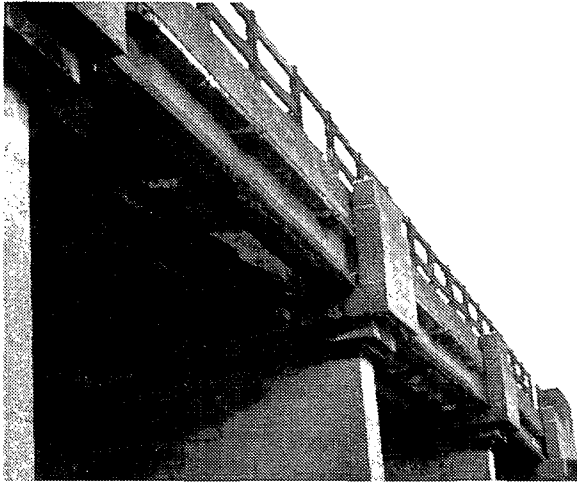


Figure 15 - Underside of girders at Adam Viaduct

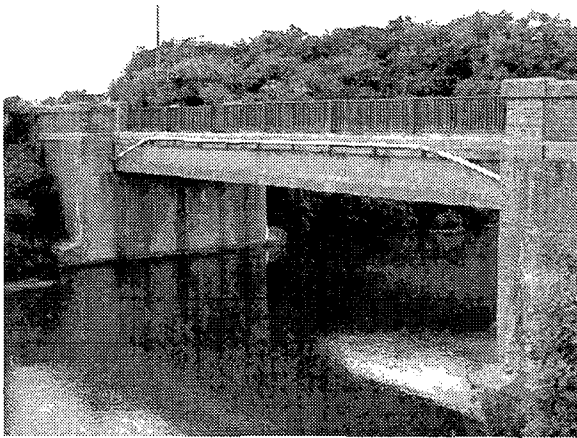


Figure 16 - Nunn's Bridge, Fishtoft

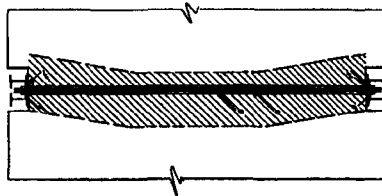


Figure 17 - Long section through church wall²⁴

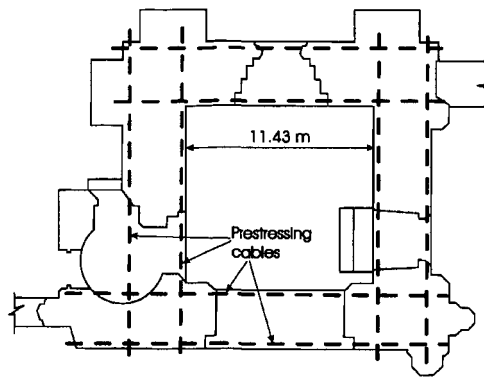


Figure 18 - Plan of Silverdale church tower showing strengthened areas (Redrawn from Reference 24)

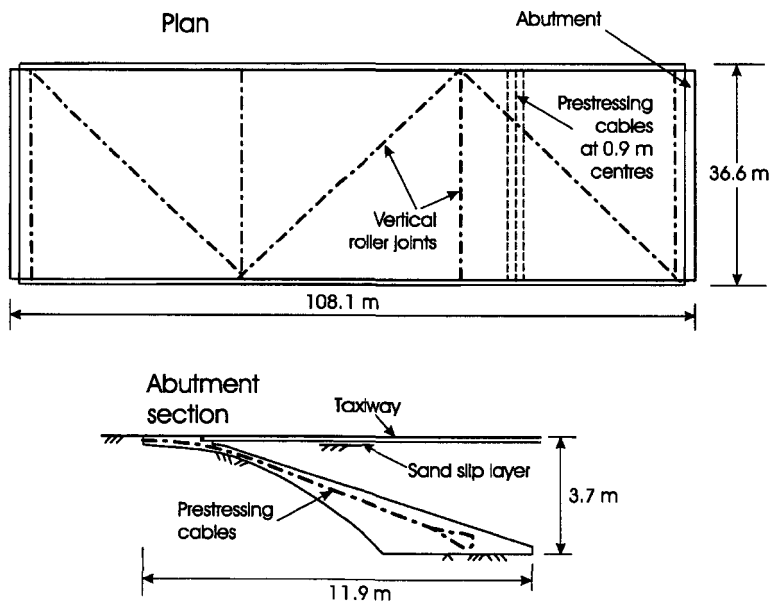


Figure 19 - Heathrow Airport Taxiway (Redrawn from Reference 28)

A Historical Review of Prestressed Concrete through Patents

by A. Schokker

Synopsis: Prestressed concrete is a relatively young form of construction in the United States. The development of the various types of prestressing materials, including anchorages was critical to the success of prestressed concrete as we know it today. This paper reviews the history of prestressed concrete with a focus on post-tensioning related patents in both the United States and abroad. Early patents from 1945 and onward are included up through the present day. The 1950's and 1960's are a primary focus as the decades where prestressed concrete was taking a foothold in the United States.

Keywords: history; patent; post-tensioned; prestressed

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INTRODUCTION

The last 50 years have seen a relative flurry of activity in the area of prestressed concrete, and particularly in post-tensioned concrete. A look at related patents gives an interesting summary of the history of post-tensioned concrete. The patents referenced in this paper are from the library of Morris Schupack who was kind enough to donate them to me. These files included correspondence detailing thoughts on various patents. Any mistakes in the reporting of these patents are mine alone. The paper does not cover every patent in the area of post-tensioning, but rather a sampling of patents from these files with a focus on patents during the early years of post-tensioning in the United States.

RESEARCH SIGNIFICANCE

1940's and 1950's

Patents related to post-tensioning exist prior to the 1940's, including the 1928 patent by Eugène Freyssinet of the "Manufacturing Process for Reinforced Concrete Components." This patent is typically considered the birth of prestress, although the term itself was not in use until years later. Another major patent from Freyssinet is "Tensioning and Anchoring of Cables in Concrete or Similar Structures" in 1945. This early anchoring system is shown in Figure 1. Freyssinet's anchorage for a bundle of single wires utilizes a cast-in cone (similar to today's trumpet behind the anchor plate) with the wires fanning out around the cone and held in place by an interior cone. Wedges are located between the wires outside the perimeter of the inner cone. A "coil" of reinforcement is included around the outer cone. The system includes details about jacking to reduce anchor seating type losses. The patent mentions that the system could be used for pretensioning or post-tensioning, but the intent is use in a post-tensioned system with a steel duct and a grease or wax coating on the wires. The files indicate that the original application for this patent was in 1940 in France and then in 1941 in the United States, with approval in 1945.

Several patents are of interest from the 1950's. Figure 2 shows a drawing from a French patent from 1951 (Dyckerhoff & Widmann) on the procedure for constructing a cantilevered post-tensioned bridge, including some basic tendon layout. Figure 3 shows an early patent for PT (post-tensioned) duct by Upson in 1954. This patent discusses the use of a flexible metal tubing that can be used in place of the practice of removable forms to form voids in the concrete for the prestressing wires. Several variations in corrugation are shown. The system is grouted and the duct shown appears to be very similar to much

of today's duct. However, the patent intends for the grouted duct to provide the anchorage of the wire with no permanent PT anchorage.

Fritz Leonhardt's 1956 patent, "Apparatus for Anchorage of Concrete Reinforcements," describes a system that utilizes separate wedges in an anchor body. The figures in the patent (one is shown in Figure 4) show a bundle of three wires within a single wedge, but the patent text includes an option for individual wedges for each wire or rod. The patent also includes a stressing system with a jack that power-seats the wedges. Daugert's 1959 patent on "Wedge Anchors" illustrates a thin, tapered wedge with teeth similar to today's strand wedges, but Daugert's wedge was intended for use on PT bars. Other anchoring patents from the 1950's include additional types of wedge systems (Stressteel, 1956) and button-head wire (or "nodule") systems (Brandt, 1959) as well as rod and bar anchoring systems (Finsterwalder, 1956; Wollcock, 1956; Lee, 1958).

1960's

A large number of patents were approved in the 1960's with a continued focus on anchoring devices, in addition to patents for stressing jacks and Prestressed reinforcement production. Correspondence found in the files with the patents included discussion about whether the wedge systems were preferred instead of the button-head system. New patents with improvements and changes to the button-head system continued to appear during these years. These include a 1965 patent by Kourkene for a button-head wire anchorage system with shims and a radially slotted anchor plate as shown in Figure 5. An expansive grout is used to hold the anchor plates in place. A recessed button-head system was also patented in 1965 by Martter. Other button-head type systems patented during the 1960's include a flat tendon system by Middendorf (1967) and a coupling device by Howlett (1967). A large number of patents with button-head systems came out during the 1960's with minor variance between them. The correspondence during this time reflects the concern that conflicts were likely to arise between companies due to the many seemingly overlapping patents.

Patents related to PT bars included a 1966 system from Middendorf for flat bars to be used as slab tendons. The bars included a deformed end, similar to the button-head anchor approach. Finsterwalder had much earlier patents on threaded bar with a nut anchorage, but the earliest patent that I had access to that showed a system similar to the PT bar systems used today was his patent from 1964, "Anchoring Means for Reinforcing Insets in Concrete." Interestingly, the correspondence included a discussion on the difficulty of finding a manufacturer for this product in the U.S. and the likely market for these bars.

While the button-head system continued to be used, patents were also being approved for a number of wedge type systems. At this point, 7-wire strand systems were also showing up in many of the patents. Rice patented a monostrand anchoring device for 7-wire strand in 1966 (Figure 6). This patent included a pocketing system similar to what was commonly being used by a number of companies at the time, causing concerns about patent infringement with the then-current practice. The validity of the patent was

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eventually questioned in a lawsuit of Atlas vs. Rice during the 1970's. Additional worries occurred over patent infringement for systems for stressing multiple wires or strands simultaneously. Freyssinet's 1945 patent for multiple strand stressing seems to have been overlooked by the patent office in the consideration of the newer patents. The 1945 patent may not appear similar to the newer multi-strand stressing patents, but the concept is very similar to the broad claims made in some of these patents. Other items, such as the inclusion of a standard grout tube also show up in claims in patents of this era even though this type of grout tube had been used in practice since the 1950's.

Other patents during the 1960's include a hydraulic jack that is capable of restressing the tendon after initial stressing (Paul, 1963) and an anchor system that includes a spiral type of anchor zone reinforcement (Kelly, 1968). La Marr patented a stressing system in 1966 for PT beam members that stresses two strands from opposite directions simultaneously as shown in Figure 7. This is similar to the procedure often used in stressing strand for Prestressed tanks. Quite a few less-than-practical patents for PT anchor systems also show up during this decade.

1970's

By the 1970's, a large number of patents for PT systems were showing up with little variation and similar to systems already in use. Some of the less-typical systems from this time included a patent by Howlett for "Multiple Tendon Anchorage" in 1970. This system used various divided anchor head configurations used as the wedging system as shown in Figure 8. Spring assemblies similar to pretensioning chucks show up for post-tensioning anchorage in several patents, such as Kelly's 1970 patent illustrated in Figure 9. This patent also shows a 3 part, rather than a 2 part, wedge. Other multi-strand anchor systems from this time include Herbschleb (1974), Brandestini (1974), Welbergen (1975), and Davison (1975). A number of jacking systems for multi-strand tendons also show up in the 1970's, including patents by Andrews (1974), Shorter (1974), and Surribas (1974).

In the area of slab tendons (both monostrand and two strand systems), patents show increasing concern for sealing the tendon. Examples include Stinton (1972), Huber (1972), Kelly (1972), Edwards (1973), and Brandestini (1976). A production method for greased and sheathed strand was patented in 1974 by Middleton. The first patent for PT grout came in 1973 by Schupack, entitled "Tendon Grouting Means." The patent describes a grout with a gelling agent to reduce bleed. A similar type of water retentive grout is still used today.

SUMMARY

A review of the patents during the early decades of post-tensioning in the United States reveals an active time in the industry. Many iterations were needed to approach the systems that are standard today (and that continue to improve). This paper provided a glimpse at several of the patents from this era, including the associated patent art.

ACKNOWLEDGMENTS

This paper was made possible by a donation from Morris Schupack of a large number of post-tensioning patent files. I appreciate his generosity and this chance to share this history of post-tensioning.

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Patents referenced in the document are arranged below in order of date. All patents are U.S. patents unless otherwise noted.

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- 1945 Tensioning and Anchoring of Cables in Concrete or Similar Structures, E. Freyssient, #2371882, 3/20/45
- 1951 Procédé de Construction de Ponts à Longue Portée en Béton Armé, Dyckerhoff, Widmann, French Patent #1039305
- 1954 Prestressed Concrete Structure, M.M. Upson, #2,677,957, 5/11/54
- 1956 Post-stressed Reinforcing Rod Anchor, Ulrich Finsterwalder, #2755657, 7/24/56
- 1956 Means for Tensioning Rods and the Like, S.R. Wollcock, #2761649, 9/4/56
- 1956 Apparatus for Anchorage of Concrete Reinforcements, F. Leonhardt, #2763464, 9/18/56
- 1956 Wedge Anchors, Stressteel Corp., Patent #218602, 9/20/56
- 1958 Bar Gripping Means for Use in the Production of Prestressed Concrete, Donovan H. Lee, Canadian Patent #553683, 3/4/58
- 1959 Post-tensioned Anchor Device, F.H. Brandt, assignor to Prestressing, Inc., #2867884, 1/13/59
- 1959 Wedge Anchors, Peter C. Dugert, #2916785, 12/15/59
- 1963 Hydraulic Jack for the Prestressing of Concrete Reinforcements, O. Paul, #3090598, 5/21/63
- 1964 Anchoring Means for Reinforcing Insets in Concrete, Ulrich Finsterwalder, #3119203, 1/28/64

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- 1965 Post Tensioning Concrete Reinforcing Wires, J.P. Kourkene, #3225499, 12/28/65
- 1965 Prestressed Tendon Anchor Means, R.P. Martter, #3225500, 12/28/65
- 1966 Method and Mean for Prestressing Concrete, K.H. Middendorf, #3255558, 6/14/66
- 1966 Apparatus for Post-Tensioning Concrete Structures, R.R. LaMarr et al, #3285569, 11/15/66
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- 1967 Prestressing Methods, J.W. Howlett, #327380, 6/27/67
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- 1970 Multiple Tendon Anchorage, J.W. Howlett et al, #3522582, 8/4/70
- 1970 Anchor for Post-tensioning Prestressed Concrete, W.F. Kelly, #3534228, 8/18/70
- 1972 Anchorage System for Stressing Concrete, Hugh Dana Huber and Jack C. Edgren, assignee Conenco Intn'l Ltd., #3685934, 8/22/72
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- 1974 Method and Apparatus for Tensioning and Anchoring Tensioning Members, James S. Andrews, assignee American Stress Wire Corp., #3787957
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- 1974 Anchoring Device for Wire Strands in Prestressed Concrete Structures, Antonio Brandestini et al, #3820832, 6/28/74

- 1974 Method of Anchoring a Bundle of Reinforcing Wires or Strands for Pre-Stressed Concrete and Anchoring Construction, Jan Frederik Herbschleb, Albert Komijn, Hans Egvert Westenberg, assignee I.B.I.S. Nederland N.V., #3822422, 7/9/74
- 1974 Apparatus and Methods for Tensioning Cables, Jorge Juan Ventura Surribas and Juan Coll Morell, #3844023, 10/29/74
- 1974 Method of manufacturing a Sheathed Cable for Use in Post-Tensioning Concrete Structures, Thomas E. Middleton, assignee pre-Stress Concrete, Inc., #3849221, 11/19/74
- 1975 Apparatus for Anchoring Wires or Stranded Wires, Gerard Welbergen and Hans Rudolf Seigwart, assignee Bureau BBR Ltd., #3863302, 2/4/75
- 1975 Multi-Strand Stressing Jack, John Davison and Hugh Jeremy Willis Edwards, assignee CCL Systems Ltd., #3868850, 3/4/75
- 1976 Anchorage Body for Anchoring Tendons with Wedges, Antonio Brandestini, Hans-Rudolf Siegwart and Gerard Welbergen, assignee Antonio Brandestini, #3956797, 5/18/76

CONCRETE AND REINFORCING THEREOF IN CONCRETE STRUCTURES

Filed Feb. 1, 1941

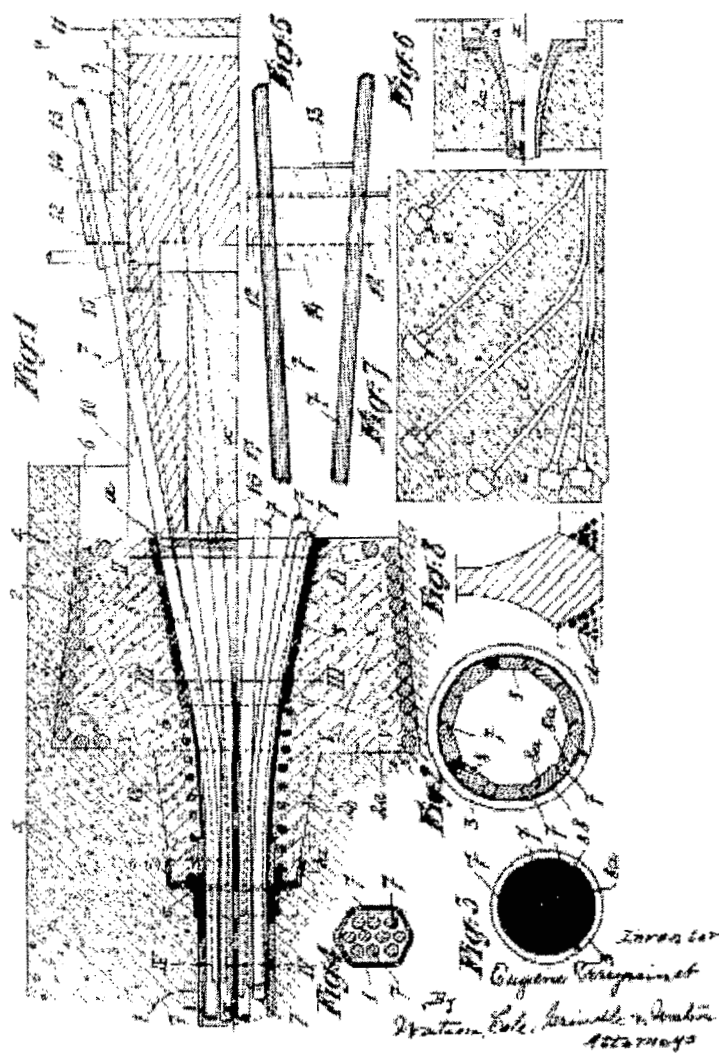


Fig. 1 – Patent Art from Freyssinet, 1945, U.S. Patent #2,371,882

N° 1.039.305

Brevet d'invention

Pl. unique

Dyckerhoff & Widmann Konstruktivgesellschaft

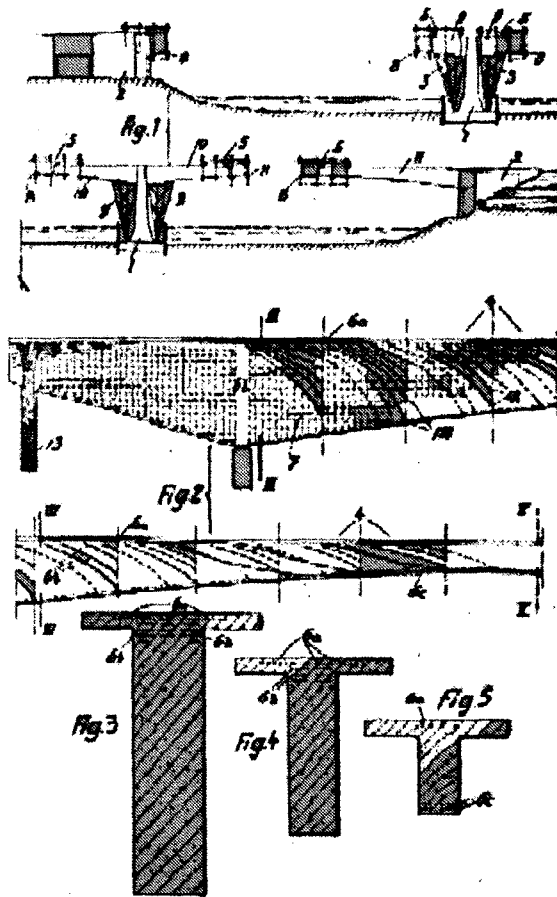


Fig. 2 – Patent Art from Dyckerhoff & Widmann, 1951, French Patent #1,039,305

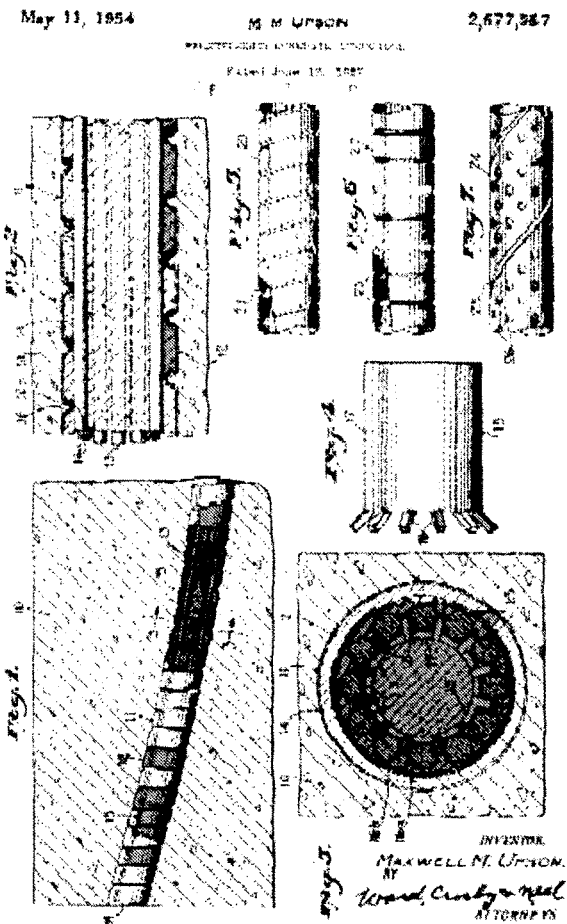


Fig. 3 – Patent Art from Upson, 1954, U.S. Patent #2,677,957