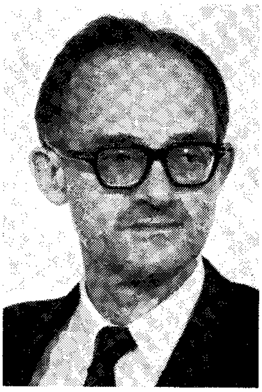
Historical Perspective on Prestressed Concrete



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The idea of prestressing, a product of the twentieth century, announced the single most significant new direction in structural engineering of any period in history.

It put into the hands of the designer an ability to control structural behavior at the same time as it enabled him—or forced him—to think more deeply about construction.

Moreover, the idea of prestressing opened up new possibilities for form. Ultimately, it is the new forms that influence the general culture, and because these forms are visual we can expect visual artists to be the first to sense a new direction.

Characteristically it was **LeCorbusier,** the most artistic of the great twentieth century architects, who first announced the new idea dramatically when, towards the end of his highly regarded *Radiant City,* written in 1933, he reported:[1]

> I hadn't seen Freyssinet for years. Then he reappeared and told me all about the precise and very demanding research project in which he had been totally absorbed all that time: the discovery of a new material entirely different from any other already in existence, five or six times more resistant than the cements and steels now in use.

LeCorbusier then quotes his friend **Eugene Freyssinet,** speaking of his discovery of prestressed concrete:

> I reached my goal. So now I'm looking around to see what I can use this discovery of mine for. And in my opinion, modern society needs *housing, parks* and *highways.*

LeCorbusier responds to this program by expressing his awe of the engineer:

> What admirable powers of divination in this man of science, of precise and audacious calculations! At a single glance—in three words—he summed up the whole program of the modern age. Into that one short sentence he has crammed a vast wealth of poetry, of lyricism, of solidarity, of concern for mankind and the hearts of men.

Synopsis

The author, who speaks fluent French and Flemish and spent some of the post World War II years in Europe studying engineering, presents an essay on the origins and development of prestressed concrete.

Three men are singled out for having had the most profound influence on the development of prestressed concrete—Freyssinet, Magnel, and Finsterwalder.

Unquestionably, it was the painstaking pioneering work of Freyssinet that convinced the engineering world of the viability of prestressed concrete.

Throughout Freyssinet's life, there is one theme that keeps recurring time and again, namely, "a simplification of forms and an economy of means."

Magnel is noted as a great teacher and for communicating his ideas on prestressing to the English-speaking world.

Finsterwalder pioneered the development of the double cantilever method of bridge construction.

In retrospect, the author regards the principle of prestressing as the single most important concept in engineering history.

The beginning of a new way of building does not usually bring forth such a florid outburst. Indeed Freyssinet's own descriptions of his achievement are entirely different, even though it too contains a passion and a vision.[2]

I decided to risk all that I had of fortune, reputation and strength in making the idea of prestressing an industrial reality. Foreseeing a long and hard struggle and a need for financial assistance, I took the precaution of taking out patents.

> The principle of prestressing is the single most important concept in the history of engineering.

He was at the time the co-manager of the large construction firm of Entreprises Limousin and M. Limousin, considering Freyssinet's ideas unsound, refused to go along. As Freyssinet later described it:

> Convinced that my attempts would soon ruin me, he considered that his friendship made it a duty for him to oppose at all cost what he considered to be folly. For me, on the contrary, this folly, even if it was to prove disastrous, was a mission that I had to fulfill whatever sacrifices might be required.
>
> At the beginning, these sacrifices were indeed considerable. I lost the best of friends, a very good financial situation, the joys given me by my profession as an engineer and the many collaborators that I had trained and loved and worse, who considered me as a deserter.
>
> At the age of 50 I was abandoning a life that was already mapped out in order to throw myself into one that was full of uncertainties and perils.

To get some idea of the type of person who would give up security to seek a new way of building, I shall give a brief sketch of Freyssinet's pre-1933 background, along with some assessment of his contributions, and a discussion of how prestressing came to America after World War II and flowered in the nineteen fifties.

For this last discussion, I shall focus on the first two major American prestressing conferences, one at the Massachusetts Institute of Technology at Cambridge in 1951 and the other at the University of California at Berkeley in 1957. Much as I would like to explore in detail the wide developments after 1957, I find these last 20 years too broad for me to make coherent in a short paper. Instead, I shall end this discourse with several contemporary examples whose purpose is to show something of the continuing nature of the European influence on American construction.

It is this last idea, often upsetting to the collective American ego, that contains a central cultural meaning of prestressing which springs from the fact that the structures of a locale characterize the local culture perhaps better than any other set of artifacts.

To focus on that fact and to narrow my scope, I shall consider here only bridges, even though we all know that prestressing has broad applications to all kinds of buildings. Still the idea of prestressing arose out of bridge design and its most impressive forms, from a purely engineering viewpoint, appear in bridges.

Eugene Freyssinet (1879-1962)

Eugene Freyssinet was born in 1879 in the provinces on the Corrèze plateau east of Bordeau in a region that he later described:[3]

> For many centuries, my ancestors lived clinging to the flanks of the steep gorges through which rush the torrents of the Corrèze plateau. A land of forests and impenetrable thickets with a harsh climate and a poor soil, it has, throughout the ages, been the refuge of the unsubdued and the rebel.

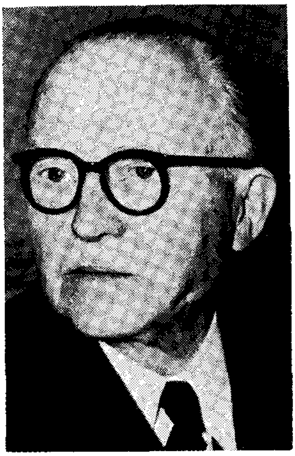
Seeing himself somewhat in that light, Freyssinet went on to conclude how his heritage influenced building and went a long way toward explaining his willingness to risk all to work out his own unconventional ideas for prestressing.

> Such conditions of background and life have formed a tough, violent and unsociable race, very poor and proud, little inclined to beg assistance and which has wrenched, from its arid soil, all that it needed to live. Universal artisans, these men have created for themselves a civilization the main characteristic of which is an extreme concern for the simplification of forms and economy of means.

Although his family moved to Paris in the mid 1880's, he never liked that city, the "abominable Paris" he called it. It did not fit at all with the artisan world whose great love was "simplification of forms and economy of means."

As a student, he was only mediocre and thus rejected in 1898 for prestigious Ecole Polytechnique which did, however, accept him the following year "with the not very brilliant position of 161st."[4] Graduating 19th, he succeeded in being accepted at the Ecole des Ponts et Chaussees where, for the first time, his artisan love of building coincided with that of his teachers, those "great artisans with an enthusiasm for their work Resal, Sejourne, Rabut." It was there, in the lectures of **Charles Rabut** in 1903-04 that the idea of prestressing first came to him:[5]

> **Freyssinet's** artisan background and love of buildings influenced him to seek an engineering solution to his structures through "simplification of forms and economy of means."



Eugene Freyssinet—More than any other person, it was the relentless pioneering efforts of this courageous French engineer-builder who converted the concept of prestressing into a practical reality.

> The idea of replacing the elastic forces that are created in the reinforcements of concrete by deflexion due to loads, by previously imposed and permanent stresses of sufficient value, came to my mind for the first time during a series of lectures given by Charles Rabut at the Ecole des Ponts et Chaussées in 1903-04. These lectures were devoted, on the one hand, to reinforced concrete and on the other, to the systematic study of spontaneous or provoked deflection in structures.

This idea never left him and served as a guide as his early career focussed on the building of bridges in the wilderness of south central France, where new ideas could flourish so long as they were based on that artisan spirit of simplification of forms and economy of means. This

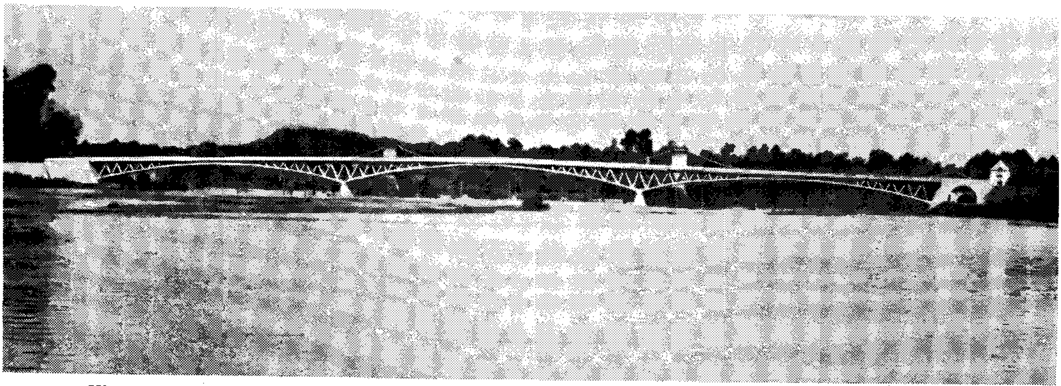


Fig. 1 Le Veurdre Bridge across the Allier River (1910-1911). Spans were 67.5-72-67.5 m (223-238-223 ft). This bridge incorporated the first use of thrust by jacks at midspan for decentering and also compensating for concrete creep and shrinkage.

was the same region in which **Gustav Eiffel,** 40 years before, had worked out new forms and economy in metal bridges.[6]

Two examples of Freyssinet's early work demonstrate both this spirit of form and the guide of prestress, the Bernard Arch of 1908 and the bridge over the Allier at Le Veurdre (see Fig. 1) designed in 1907 and completed in 1912.[7]

> Towards 1906-07, the idea of applying precompressions was firm enough in my mind to lead me to draw up a project for a 2500-ton capacity tie linking the two abutments of a 50-m span trial arch.
>
> This tie and its arch were completed during the summer of 1908 but a study of their deflexion and other observations taught me the existence of creep in concrete, a phenomenon that was then unknown and even energetically denied by official science. In case of induced permanent stresses, this was a fearsome unknown. Immediately and as carefully and completely as possible, I began to study this problem but my efforts were rendered vain by my mobilisation in August 1914.

At Le Veurdre, the situation was more dramatic and the impact on Freyssinet's vision more lasting. He had volunteered to build three bridges over the Allier River for a price exactly one-third of that which had been bid. As a local engineer of the highway department, he had suggested that the bids be rejected and that he be allowed to act as the builder for these bridges following his own designs.

As Freyssinet later described it:[8]

> Fifteen days later, an official letter put me in charge of supervising, on behalf of the Public Authorities, the execution of these bridges whose designer I was, for which I was to be the contractor and the plans of which had never been submitted for anyone's approval. Mercier [Freyssinet's superior] then left for Portugal granting me unlimited credit out of his funds but without giving me a single man, tool or piece of advice. Never was a builder given such freedom. I was absolute master, receiving orders and advice from no-one.

This rather frightening responsibility had an even more frightening conclusion when several months after completion of the three-span bridge at Le Veurdre, the 72m (238 ft) span arches began to deflect downward at an accelerating rate.[9]

> To halt this, all that was required was to remove these joints [at the arch crown] after having, by using

my decentering [sic] jacks in a new application, sufficiently raised the crowns of the arches to do away with the major part of the increases of stress resulting from the deformation of the neutral axis of the arches. There could be no question of informing the Head Engineer or the Prefêts in order to halt traffic for they would have panicked and paralysed me and any day that passed might bring total collapse for, at this moment, the strains were increasing at a frightening rate.

These jacks, the so-called Freyssinet flat jacks, are still used in major structures today such as, for example, in the gigantic prestressed CN Tower in Toronto; Freyssinet placed them in the crown hinge and as he went to describe it:[10]

Returning to Moulins in the night, I jumped onto my bicycle and rode to Veurdre to wake up Biguet and three reliable men. The five of us then re-inserted the decentering [sic] jacks—I had always kept this possibility in reserve—and as soon as there was enough daylight to use the level and staffs; we began to raise the three arches simultaneously. It was market day and every few minutes we had to interrupt the operation to allow a few vehicles to pass. However, all ended well and once more aligned, cured of the illness that had almost killed it, the Veurdre bridge behaved perfectly until its destruction in the war in 1940.

Writing in 1949, about the companion bridge at Boutiron, Freyssinet stated that:[11]

I have just seen it again and even after [my larger and more recent arch bridges] I consider it. since the disappearance [sic] of Le Veurdre, to be the finest of my bridges.

In the process of creating these wilderness works, Freyssinet laid the essential basis for prestressing

Had **Freyssinet** never pursued the idea of prestressing, he would still have been regarded (along with Robert Maillart) as one of the two greatest concrete structural engineers in the first half of the twentieth century.

which, however, had to await almost 20 years before it became more than just a special method of arch construction.

During the 1920's Freyssinet designed a series of arch structures that made him a world figure, not only to engineers, but to architects and artists as well. Had he never pursued the idea of prestressing, he would still have been regarded, along with **Robert Maillart,** as one of the two greatest concrete structural engineers in the first half of the twentieth century.[12]

The bridge over the Seine at Saint-Pierre du Vauvray, completed in 1922, set the world's span record for concrete arches at 131 meters (432 ft) and followed Freyssinet's method of jacking the arch apart at the crown to compensate for rib shortening and to lift the structure off the scaffold.

Then several years later, he won a competition for a far larger project, the spanning of the Elhorn river at Plougastel, a project which occupied him until 1930. Here, Freyssinet designed three hollow-box arches each of 186 meters (614 ft) in span (see Fig. 2) and again the arches were jacked apart at their crowns by a controlled prestress.

It was in the course of studies for this impressive project, that he took up the study of creep and shrinkage in concrete:[13]

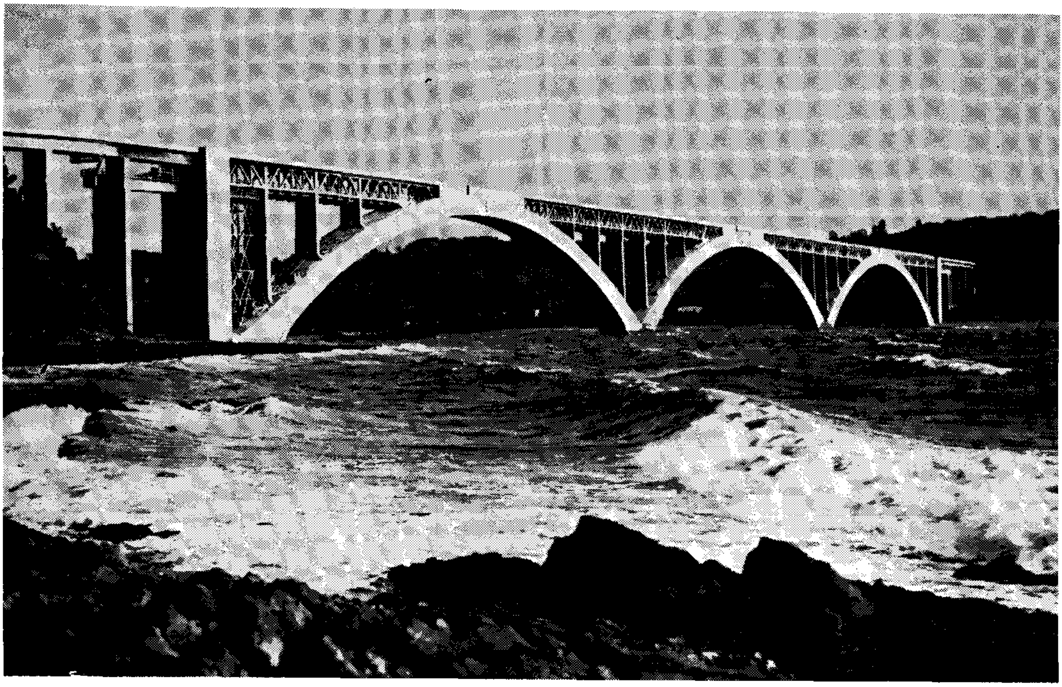


Fig. 2. Plougastel Bridge across the Elorn River (1930). Three spans of 180 m (584 ft). This bridge had the largest span in reinforced concrete at that time.

> . . . to know whether one could create permanent prestresses in concrete in spite of its slow strains . . .

Here was a statement of the problem somewhat more general than the specific question of designing arches. Thus, in 1926 he organized a set of experiments and began research which was published posthumously as "the Relations Between the Strains and Constitution of Cements and Colloidal Structured Materials" (1926-1929).[14]

Freyssinet's motivation was primarily to understand structures made of concrete rather than the structure of concrete. Indeed he ends this treatise with the conclusion that "arches with spans in excess of 1000 meters" can be built "at a far lower cost than a suspension bridge of the same span."[15] His major work did not, however, lie in that direction.

By 1928, with Plougastel well under way, Freyssinet had recognized the more general significance of prestressing, patenting his ideas in France, Britain, and the United States.[16] For the next 4 years, he devoted his full attention to the potentials of prestressing.

In November of 1932, Freyssinet sat down and wrote out his progress at the request of the editor of a new journal *Science et Industrie.* In one of its early issues, dated January 1933, Freyssinet's article "New Ideas and Methods" appeared.[17]

Beginning with his ideas on the "thermodynamic theory of binders," he proceeded to analyze the behavior of cement, of concrete, and of reinforced concrete all from the perspective of a scientist. He described tests and their results and further explained how stresses over a cross section arise from shrinkage, from axial compression and from bending. Finally, in the fourth of his six chapters, he outlined the "conditions for the practical use of prestressing."[18]

1. Using metals with a very high elastic limit.

2. Submitting them to very strong initial tensions, much greater than 50 kg/mm^2 (70,000 psi).

3. Associating them with concretes of a very low, constant and well-known rate of deformability, which offer the additional advantage of very high and regular strengths of resistance.

In present-day terms, Freyssinet had established the need for high strength steel, for tensioning it to a high initial stress, and for high strength concrete to reduce to a minimum the loss of initial prestress.

Although many engineers had proposed the idea of prestress even as far back as 1886, no one had based his idea on a clear understanding of the properties of the concrete. Thus, all previous ideas had failed to produce what is now called prestressed concrete.[19]

Freyssinet saw, in general, the wide potential for his idea, which used what he called *treated* concrete, but in particular, he had great difficulty in establishing any commercial value for it. Partly of course, 1933 was the depression, but partly too it was a genuinely radical idea. Seen as a means for improving arch design, his system of crown jacking was accepted both in Europe and the United States and used as early as 1930 in Oregon;[20] but seen as a new material, prestressing found little application in its early years.

Freyssinet himself developed a factory at Montargis where he manufactured prestressed concrete poles (see Fig. 3) for electric lines, but he could not make it succeed. The factory closed not long after his 1933 article appeared and as Freyssinet later put it "our factory was without customers and was only good for scrap; my wife and I were ruined."[21]

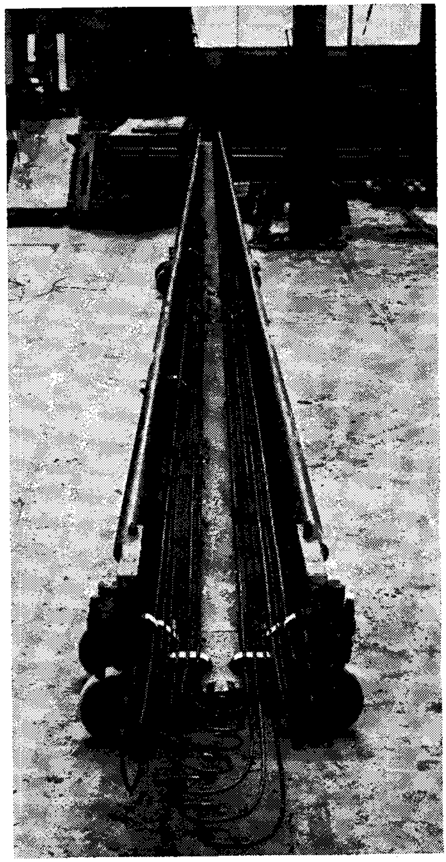


Fig. 3. Production of prestressed concrete poles (1933).

But not for long, because in 1935 he had the opportunity to prove the merits of prestressing by saving the Martime Terminal at Le Havre, parts of which had been settling into the harbor at the alarming rate of about 1 in. (2.54 cm) per month.

Freyssinet proposed to consolidate the foundations by prestressing and his success so convinced the French authorities that they then supported numerous large-scale projects between 1935 and 1939 where prestressing proved its practical merit. Freyssinet's retrospective attitude on

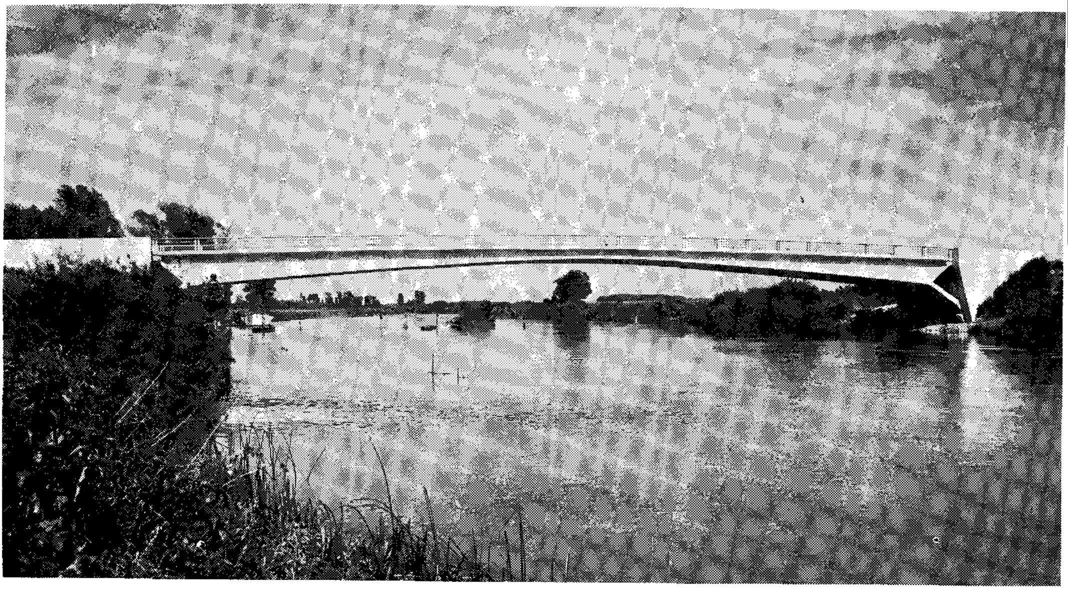


Fig. 4. Armet Bridge across the Marne River (1946). This elegant bridge (built by Freyssinet) was the first major bridge built of precast prestressed segmental construction.

the Marine Terminal restorations is intriguing:[22]

> Would I have had the courage to take responsibility had this not constituted for me too, the only chance of rescuing from oblivion the techniques that had cost me my fortune and five years of the hardest work . . . it was perhaps a chance of saving my confidence in myself and in the worth of my effort.

Here Freyssinet intimates the role that chance plays in providing opportunities even though eventual success surely depended upon those long years between 1903 and 1933 of direct field experience in structures. But Freyssinet's ability to transform his ideas into new structures lay less in chance or even in long experience. As he himself said of those experienced engineers before him who had had the notion of prestressing:[23]

> When by chance, they approached this domain, the absence of a *directing idea* prevented the drawing of conclusions that were of any practical consequence.

This directing idea, for Freyssinet, was in general that simplification of forms and economy of means so characteristic of his artisan heritage; or as he said once to young engineers:[24]

> I loved this art of building which I conceived in the same way as my artisan ancestors, as a means of reducing to the extreme, the human toil necessary to attain a useful goal . . . from the bridges of Septfonds and LeVeurdre to those of the Marne (see Fig. 4) and Caracas . . . (two of his best-known post World War II bridge projects) . . .

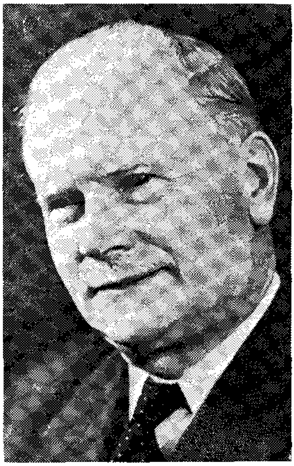
More specifically this love went to define prestressing as an entirely new material with the widest possible application. For Freyssinet "the fields of prestressed and reinforced concrete have no common frontier;" either a structure is fully prestressed *or it is not to be called prestressed* concrete.

We do not need to accept that

rigid definition today to recognize how essential it apparently was to Freyssinet to have this idea of prestressing as a new material in order to direct his energies into practical applications. It was to be crack free; a structure in which the elongation of the high strength steel was to be independent of the strain in the concrete.

One has only to read his writings to realize that Freyssinet was more an advocate than a teacher; more an originator of ideas than one who explains them to others. In his writings, he can even now communicate clearly to us his passion but not so well his technical concepts.

It took another sort of person to make clear the simplicity of prestressing and especially to bring it to the United States. Probably the most influential engineer to do this was **Gustave Magnel.**



Gustave Magnel—This multi-talented Belgian professor combined his design, research, teaching, and writing skills to communicate his knowledge of prestressed concrete to the English-speaking world.

Gustave Magnel (1889-1955)

After having graduated from the University of Ghent in Belgium, Magnel spent the years of World War I in England where he helped train British engineers in reinforced concrete. Aside from establishing his teaching talent, this experience gave him a full command of the English language.[25]

In 1922, Magnel was appointed a lecturer at Ghent to teach reinforced concrete, in 1927 named docent, and in 1937 made professor and director of the Laboratory for Reinforced Concrete.[26] Although French was his mother tongue, he switched his teaching to Flemish (Dutch) when the University at Ghent changed languages in the late 1920's. He could thus teach fluently in at least three languages.

In addition to teaching, he was a prolific writer, an experienced designer, and an able researcher by the time the second World War isolated him in Belgium. During those years then he began to explore Freyssinet's ideas and to carry out some research on his own.

Thus, when the war ended and building in Europe began again at an accelerating rate, Magnel was one of the few engineers with long experience in reinforced concrete, who at the same time had mastered the ideas of prestressing, and what is even more important, who was ideally suited to communicate those ideas to the English-speaking world.

He had already written at least nine books, some of which had gone through three editions when, in 1948, he wrote *Le Beton Precontraint* which was immediately published in

The single most significant characteristic of **Magnel** was his ability to communicate as exemplified by his teachings, and prolific writings—and more importantly to translate those ideas to the English speaking world.

Freyssinet and Magnel in Contrast

Magnel's books and writings (English editions) clearly explain the idea of prestressing in terms of structural mechanics, whereas Freyssinet in his 1949 article gives a more descriptive, but less practical, discussion.[28]

Freyssinet's writing is more stimulating to an experienced engineer, Magnel's more useful to one unacquainted with prestressing.

Whereas Freyssinet saw prestressed concrete as a completely new material, essentially different from reinforced concrete, Magnel emphasized rather the simplicity of design as it related to the, by then accepted, ideas about reinforced concrete.

Freyssinet exhorts the designer to rethink concrete structures from a totally new perspective while Magnel demonstrates how procedures already known by a practicing engineer in 1948 can be used to design members of prestressed concrete.

English, went through three British editions and was also later published in the United States.[27]

But the single most significant characteristic of Magnel was his ability to teach. As one of the few Americans who followed a complete sequence of his courses at Ghent, I can state that he was the best teacher I ever had. His efforts in teaching, writing and research were to simplify. As he wrote in his book on prestressing:[29]

> In the writer's opinion this problem (of computing the ultimate strength of prestressed beams) should be solved with the least possible calculations, as calculations are based on assumptions which may lead to wrong results.

His suspicions of complex calculations was balanced by his confidence in tests and full-scale observations.

> It is therefore proposed to use known experimental results to produce a reasonable formula, avoiding the temptations to confuse the problem with pseudo-scientific frills.

It was this drive for simple, practical formulas and explanations which, combined with his long experience, lent credibility to Magnel's enthusiasm of prestressing. Thus, when the opportunity arose in 1948 to explore the possibility of building a major public structure of prestressed concrete, it was not surprising that the American engineers involved would turn to the Belgian, Magnel, for a design.

The Walnut Lane Bridge

In a speech given at the First United States Conference on Prestressed Concrete, **Samuel S. Baxter,** later to become president of the ASCE, stated that had the original arch design for the new Walnut Lane Bridge been bid below the engineers estimate:[30]

> It is also quite possible that this First Conference on Prestressed Concrete might not now be in session . . .

His claim was probably correct, even though prestressing was already being tried out by 1951 and some conference would soon have been arranged thereafter. Still this Philadelphia bridge served to characterize the potential for prestressed concrete because of its large-scale, 160-ft main spans, because of its construction economy, and because of its acceptance, not only by city engineers, but also by a powerful city Art Jury, two types of people normally associated with traditional attitudes.

As Baxter explained it, the stone-faced arch design of 1974 obtained a low bid of $1,047.790 compared to the engineers estimate of $900,000. By law, if the low bid exceeds the estimate, it is rejected. Thus, the city engineers began to search for another solution, of which two arose.

The first was a plan to remove the stone facing which in the low bid amounted to the astounding sum of $486,490! Here the Art Jury objected to the mass of an unfaced arch. The second solution suggested itself almost by accident.[31]

> The Bureau of Engineering, Surveys and Zoning at that time was constructing large circular sludge tanks at its new Northeast Treatment Works. These were being built by the Preload Corporation of New York (sub-contractors for Virginia Engineering Company of Newport News, Virginia), using the prestressing technique of winding wires around a thin core. The chance remark of Mr. E. R. Schofield, who was at that time Chief of the Design Division of the Bureau of Engineering, Surveys and Zoning, to a representative of the Preload Corporation, led to a decision to explore the use of prestressed concrete for this bridge. Among those with whom Mr. Schofield talked were Mr. L. Coff, Consulting Engineer of New York, and representatives of the Preload Corporation. Contracts were also made with Professor Gustave Magnel in Belgium.

The city decided to follow Magnel's ideas for a prestressed concrete girder design but they still had to convince the Art Jury. Baxter records their response, surely one of the most historcally significant events in the relationship between structure and aesthetics.[32]

> The Art Jury, however, on seeing the preliminary sketches for the new bridge agreed that the comparatively slim lines of the new bridge would not require stone facing.

Thus, a major structure in one of Philadelphia's most elegant natural settings became possible because its appearance was pleasing enough to permit it to be economical. The low bid in 1949 was $597,600 for the bridge and $100,783 for the approaches; Baxter estimated that this amounted to a "net minimum saving (of) approximately $76,000" over an arch without stone facing in 1949.[33]

Moreover, the Art Jury would probably have required a rubbed finish on the bare concrete arch, adding at least $40,000 and making the prestressed solution a minimum of $116,-000 less than the arch. The saving of over 16 percent clearly made this large-scale work possible and influenced the way prestressing entered American practice. Of the thirty papers presented at MIT in August of 1951, five were by people directly connected to the Walnut Lane Bridge.

Another feature of this bridge was the full-scale test to destruction of one of its 160-ft (48.5 m) long girders. Although, perhaps, unnecessary in principle, this test did serve dramatically to demonstrate, in practice,

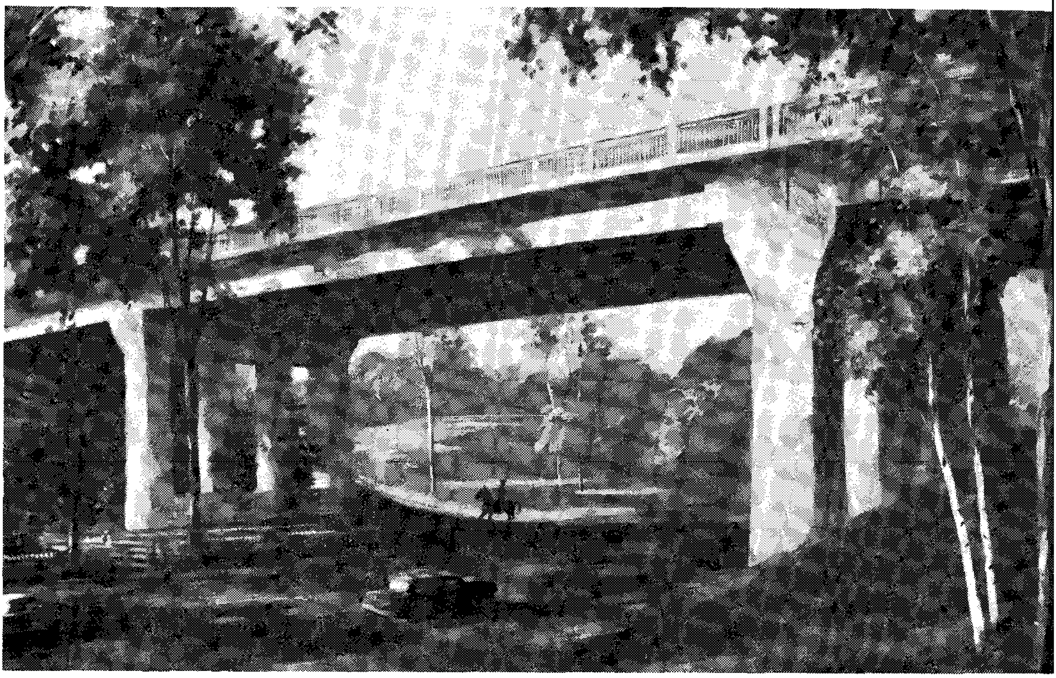


Fig. 5. Artist's painting of Walnut Lane Bridge after completion (1951).

Particulars of Walnut Lane Bridge

The first prestressed concrete bridge to be constructed in the United States was Philadelphia's Walnut Lane Bridge. This bridge, which was conceived and designed by Gustave Magnel, was completed in 1950. It contains three simply supported girders with a center span of 155 ft and two end spans of 74 ft each. The girders are I-shaped, 79 in. deep with 52-in. flanges.

The flanges in the center span are butted, but in the end span the beams are placed 8 ft 8 in. on centers and the slab cast-in-place. The girders were tensioned by the Magnel method, i.e., using two strands **at a time.**

The Preload Co. of New York erected this structure. The girders were cast on falswork at the bridge site and moved horizontally into position on the foundation.

and in front of at least 500 engineers, the high overload capacity of the bridge built along these new lines.[34]

Fig. 5 is an artist's picture of the Walnut Lane Bridge soon after completion in 1951. Fig. 6 is a shot of the same bridge taken in 1976.

Thus, the Walnut Lane Bridge put before the American structural engineer the image of new possibilities for safe, economical, and elegant structures. Yet these obvious advantages came together with a set of questions even doubts, that all centered on a suspicion of European ideas that has existed in America at least since the time of Emerson's American Scholar speech of 1837. In Emerson's terms, the doubts focussed on the need to think deeply about the local American environment and to create works of art, political structures and scholarship that would be distinct and original rather than merely copying European taste.

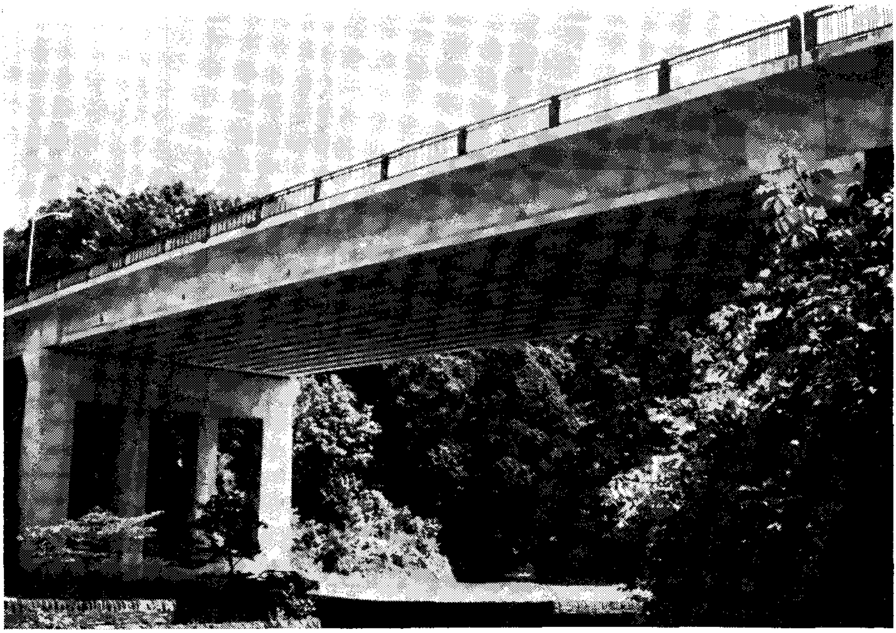


Fig. 6. Walnut Lane Bridge as it appears today (1976).

In modern engineering terms, these doubts center on the difference between labor and materials. Labor being cheaper in Europe means that material savings dominate design ideas, whereas materials being cheaper in America, labor savings are supposed to dominate design ideas in the United States.

We need to look critically at these cliches today. They reflect in part a questionably conservative attitude toward design and a justifiably cautious attitude toward building.

The Walnut Lane Bridge raised again this question of labor and materials and it was criticized for being too much a European design. Magnel had made the design through the Preload Corporation whose vice president Cruzon Dobell reported that "it took 152 man hours to assemble and install one ton of prestressing wire" for the bridge.[35]

Magnel, himself, was astounded at the problems associated with getting American industry to manufacture special fittings. He used to lament that all would have been well, if instead of 20 end cable fittings, he could have ordered one million!

Admiral Jelley, Chief of the Bureau of Yards and Docks, perhaps summarized best this viewpoint in his

In the immediate post World War II years, there was a widely held view that labor being cheaper in Europe meant that material savings dominated design ideas, whereas materials being cheaper in America, labor savings were supposed to dominate design ideas in the United States.

FORMATION OF FIP

The Federation Internationale de la Precontrainte (FIP) was officially inaugurated at a meeting held at the University Engineering Department, Cambridge, England, on August 29, 1952.

This meeting represented the culmination of the efforts of several eminent international engineers and research workers who had held meetings and discussions over a 2-year period, and in which **Eugene Freyssinet** and **Gustave Magnel** played prominent roles.

Most fittingly, the first president of FIP was Freyssinet and the first deputy-general vice-president was Magnel.

Today, FIP has Member Groups in 44 countries and FIP observers in some 25 other countries. The current president of FIP is **Ben C. Gerwick, Jr.** of the University of California at Berkeley.

One of FIP's principal activities has been to organize international congresses and special symposia throughout the world. It has held Congresses in London (1953), Amsterdam (1955), Berlin (1958), Rome and Naples (1962), Paris (1966), Prague (1970), and New York (1974). The eighth Congress will be held in London in May 1978.

"Closing Summary" to the MIT Conference:

> We have seen American adaptations of European practice in bridge construction. The Walnut Lane Bridge in particular was a direct application of Dr. Magnel's system.
>
> However, the Arroyo Seco foot bridge (California's first prestressed bridge) had an interesting departure from European precedents—a button type of anchorage was used. I think that this is significant because I consider that European ideas should not be copied blindly. Construction conditions in this country, particularly trade practices, preclude this. American engineers must find and develop their own solutions.

This was the situation at the end of 1951. The idea of prestressing was well accepted. Its safety and economy seemed possible and its visual potential a reality. Now began the long process, even now unfinished, for American engineers to find and develop their own solutions.

Developments 1951-1957

In his 1951 discussion at MIT, **W. E. Dean** noted that in following a prestressed design through to calculations and plans:[36]

> We encounter a number of factors that are puzzling to say the least. All of these are capable of solution and it is evident that our European counterparts have solved them to their satisfaction, but whether we can adapt our practice and concepts of safety to European thinking remain to be seen.

This skeptical view, common among structural engineers in 1951, had by 1957 changed radically as Dean himself expressed in the opening speech of the *World Conference on Prestressed Concrete* held in Berkeley in July 1957:[37]

> Those who have been associated

with the prestressed concrete field for the past several years have reason to be proud. Their past efforts have been spectacularly satisfying, present development is stimulating, the future appears to be not only promising but almost fantastic in its potential for the use and maturity of prestressed concrete design. For in the utilization of this economical, versatile and highly adaptable material we are barely coming of age.

The intervening years brought prestressed concrete into the mainstream of American construction practice; it moved from the province of the pioneers such as Freyssinet and Magnel into the practice of all structural engineers.

In the United States, those 6 years saw the organization of the Prestressed Concrete Institute at Tampa, Florida, in July of 1954, the publication of the first specification for pretensioned prestressed concrete on October 7, 1954, by the PCI and in the same year the "Criteria for Prestressed Concrete Bridges" by the Bureau of Public Roads; and the appearance of American textbooks on prestressed concrete structures, the most widely used being that by **T. Y. Lin,** written largely during his one-year Fulbright Fellowship at Ghent with Gustave Magnel.

These events were the evidences of the rapid growth of prestressed concrete throughout the United States and the World; and it was this growth that the Berkeley Conference summarized in the summer of 1957.

Five reports on American bridges appeared and they characterized well the developments since 1951:

First, a discussion by **Arthur L. Elliott** on construction experience with prestressed concrete in California where the state bridge department had already contracted for over 60 projects.[38] Elliott focussed on their problems, especially with inexperienced contractors, but clearly showed that his bridge division had made major progress in using the new ideas.

The second report by **E. L. Erickson,** chief, Bridge Division Bureau of Public Roads, described the newly published "Criteria for Prestressed Concrete Bridges," which had already played a central role in encouraging bridge designers to try prestressing and which was beginning to open up its design for bridges of the interstate highway system enacted into law by the Congress in 1956.[39]

The third report by **Wayne F. Palmer,** described "The 24-Mile Lake Pontchartrain Prestressed Bridge" recently completed near New Orleans.[40] This immense project signalled the practicality of pretensioned precast elements and proved

FORMATION OF PCI

The Prestressed Concrete Institute (PCI) was organized at a special meeting in Tampa, Florida, July 1954. Two years later the first issue of the PCI JOURNAL was published.

In November of 1959, the PCI moved its headquarters to Chicago.

Today, the PCI is an umbrella organization made up of over 2000 producer and supplier companies, affiliated state associations, professional engineers and architects, and students.

The current president of PCI is Chicago-based consulting engineer **Eugene P. Holland.**

Major International Prestressing Conferences In North America

First United States Conference on Prestressed Concrete, Massachusetts Institute of Technology, Cambridge, Mass., August 14-16, 1951.

Canadian Conference on Prestressed Concrete, Toronto, Ontario, January 28-29, 1954.

World Conference on Prestressed Concrete, University of California at Berkeley, Calif., July 29-August 3, 1957.

FIP/PCI Congress, New York, N.Y., May 26-June 1, 1974.

ACI-CEB-PCI-FIP Symposium, ACI Annual Convention, Philadelphia, Pa., March 31-April 1, 1976.

T. Y. Lin Symposium on Prestressed Concrete—Past—Present—Future, University of California at Berkeley, Calif., June 5, 1976.

by competitive bidding to be substantially cheaper than the competitive bid in steel. As Palmer put it:[41]

> When bids for both the steel and the concrete designs were opened, it was clear that on a project of this kind steel was no longer a serious competitor.

The fourth report dealt with the bridges for the Illinois toll highway on which the decision had been made to standardize precast factory-made prestressed elements for 224 of the 289 bridges.[42] Again comparisons with steel designs indicated the economy of prestressed concrete. For the prestressed concrete bridges, the unit costs were $13.10 per sq ft whereas for the steel $16.50 per sq ft, a very substantial difference.

The fifth and final American report on bridges described a full-scale load test of one bridge for the Illinois toll highway.[43]

What these reports show is a major shift in focus, compared to the bridge reports at the MIT Conference 6 years earlier, a shift away from individual custom-made projects like the Walnut Lane Bridge and towards mass produced fabrication on immense projects or, as in the case of California, the wide use of prestressing by a single public agency. There is no mention of the Walnut Lane Bridge in any of these articles and very little reference to European experience. As Dean stated in his opening remarks:[44]

> It appears that in the field of relatively small standardized, mass produced parts, United States construction is presently outstanding. In long spans, continuous structures and the more daring structural applications, foreign technology leads.

As if to pick up Dean's challenge about Europe's lead in daring structures, **T. Y. Lin,** the Conference Chairman, closed the proceedings by presenting a set of drawings by an architect for daring structures of prestressed concrete. Lin's own career since 1957 bears out clearly the positive results of such futuristic stimulus.

What I wish to add here is the parallel stimulus of looking back at some equally dramatic design ideas which arose during those early years before the Berkeley Conference. Especially important are the ideas of

Ulrich Finsterwalder, who during that same period in the 1950's took prestressing and made it a construction technique as well as a design idea.

Ulrich Finsterwalder

Finsterwalder, like Freyssinet, is a builder whose designs have frequently been constructed only because they were bid below other competing designs. His major bridge idea, developed after World War II, is the double cantilever, built entirely without scaffolding. Figs. 7 through 12 show several of his major works.

Like Freyssinet and Magnel, Finsterwalder came to prestressing with a long experience in reinforced concrete and especially like Freyssinet, in arch and thin shell structures. Finsterwalder learned mathematics while in a French prison camp during World War I and after the war he put that to use in shell theory which served as a basis for the many thin shell concrete structures designed and built by Dyckerhoff and Widmann A. G. starting in the mid 1920's.

In 1937 he began work developing a prestressing system and designed and built his first bridge.[45] Then after World War II, his major prestressing work began, which he reported on in America in 1952.[46]

His work since that time is so broad and varied that it defies simple characterization, except to say that more than anyone else, perhaps, Finsterwalder has shown that prestressed concrete can be a safe, economical, and elegant solution to almost any major structural problem that exists in the modern world.

In a 1970 interview, Finsterwalder mentioned that his favorite bridge was the Mangfall Bridge, under design just at the time of the Berkeley Conference. With this bridge, as in other cases, Finsterwalder sought to show that prestressed concrete could compete directly with steel, not only in cost, but also in the reduction in its depth.

Ulrich Finsterwalder—This imaginative German engineer-constructor has played a very significant role in advancing the state-of-the-art of prestressed concrete especially his development of the double cantilever method of erection in bridge construction.

In the Mangfall, built by his cantilever method but made with open truss-like walls, his idea was to duplicate the girder depth of the steel bridge built in the late 1930's and destroyed in World War II. Not only did he succeed technically, but in designing a two-level bridge (Fig. 9), he provided the pedestrian with one of the most spectacular crossings since the Brooklyn Bridge.

Finsterwalder has the idea of providing a prestressed concrete alternative to every steel bridge design including those with very long spans which have previously been the sole

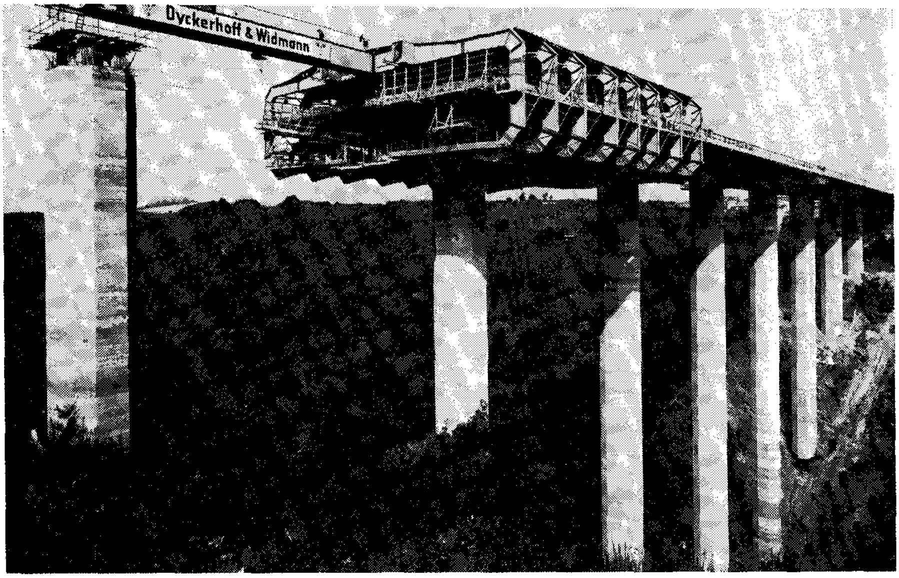


Fig. 7. Elztal Bridge (1965).

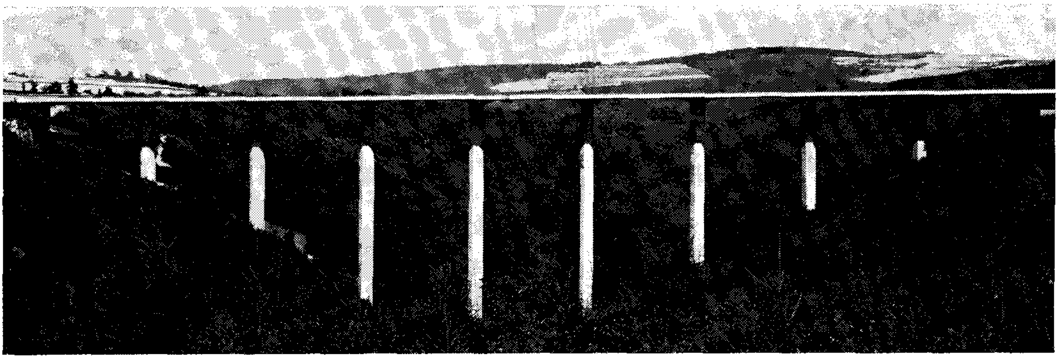
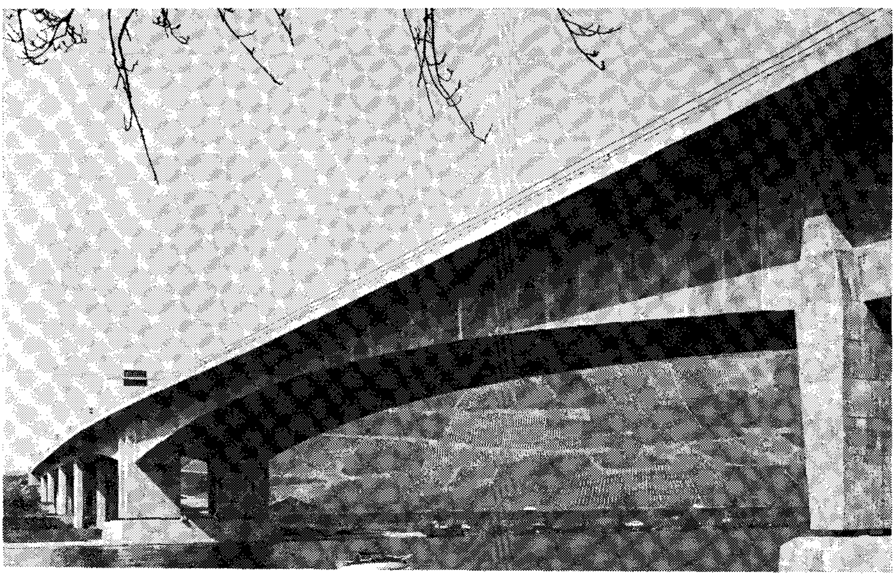


Fig. 8. Mosel Bridge (1965) at Schweich-Longuich.



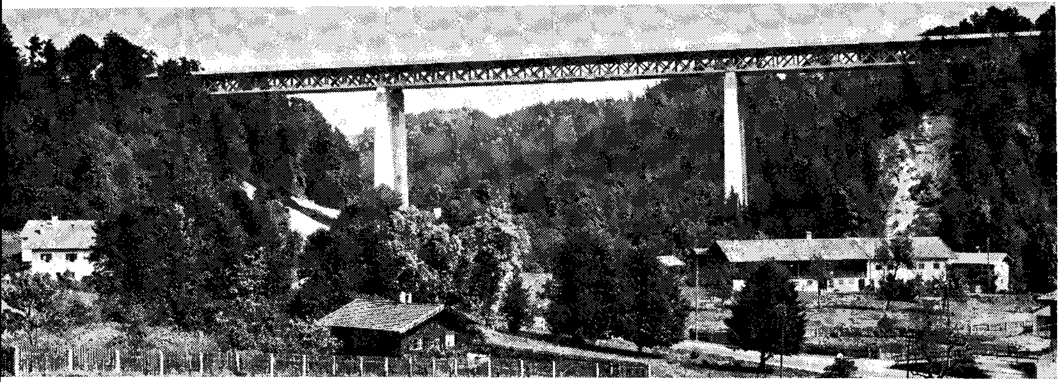


Fig. 9. Mangfall Bridge (1947) at Darching.

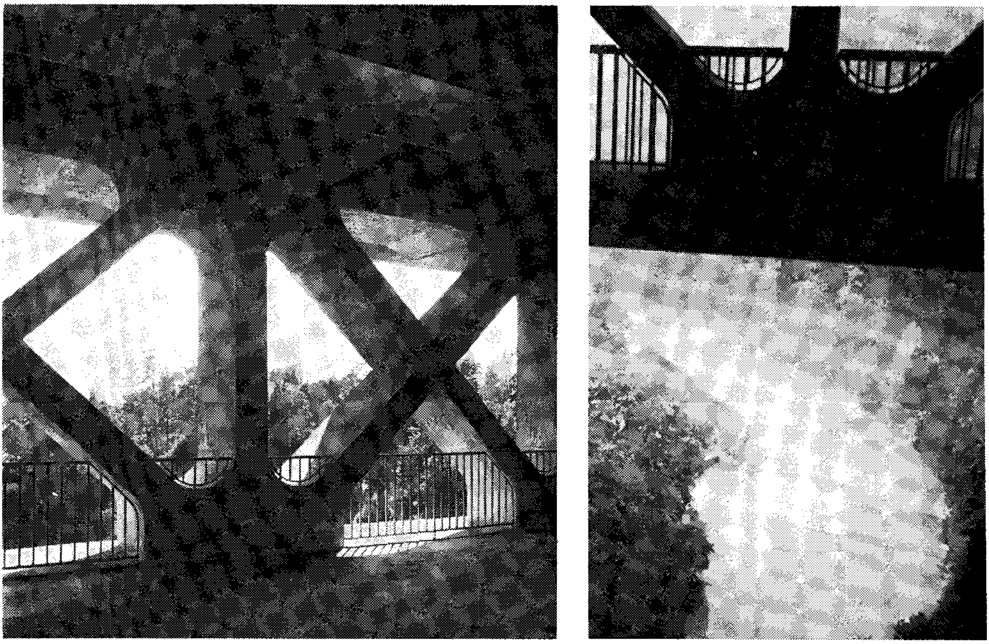
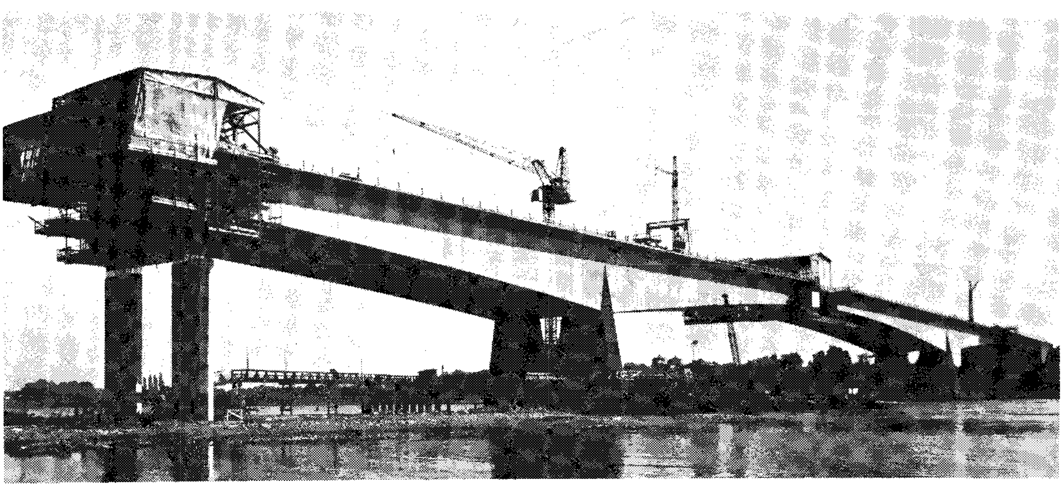


Fig. 10. Bendorf Bridge over Rhine (1962).



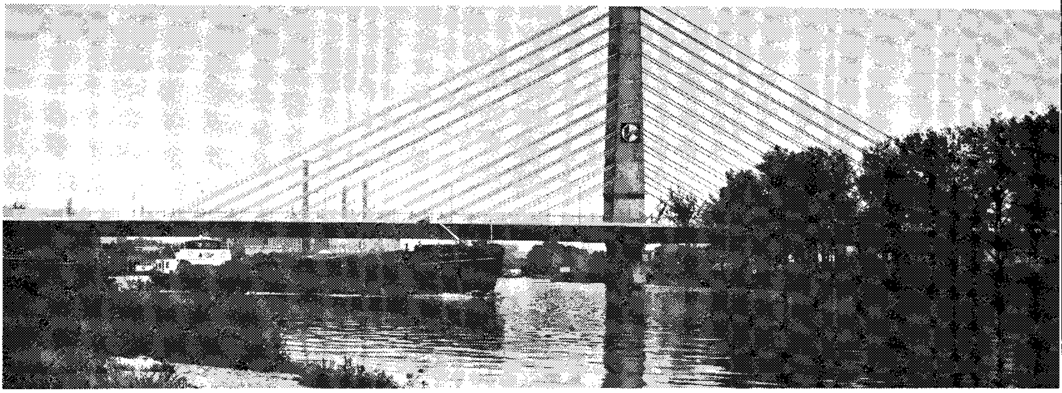


Fig. 11. Second Main Bridge (Frankfurt-Sindlingen).

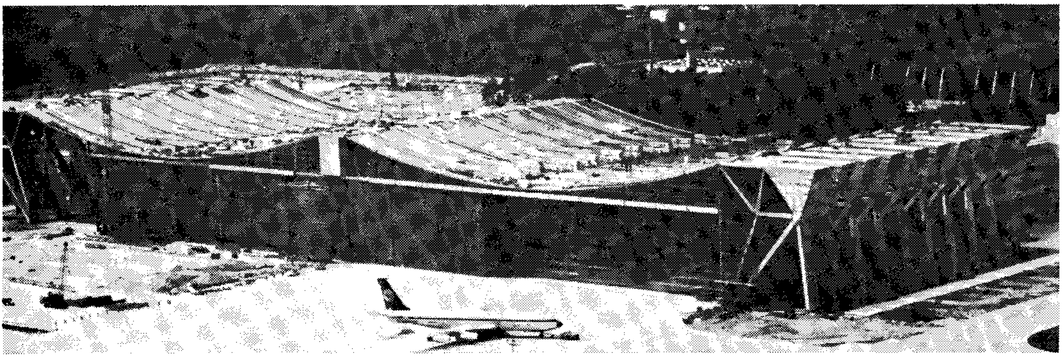


Fig. 12. Rhein-Main-Flughafen Airport Terminal (1968) near Frankfurt.

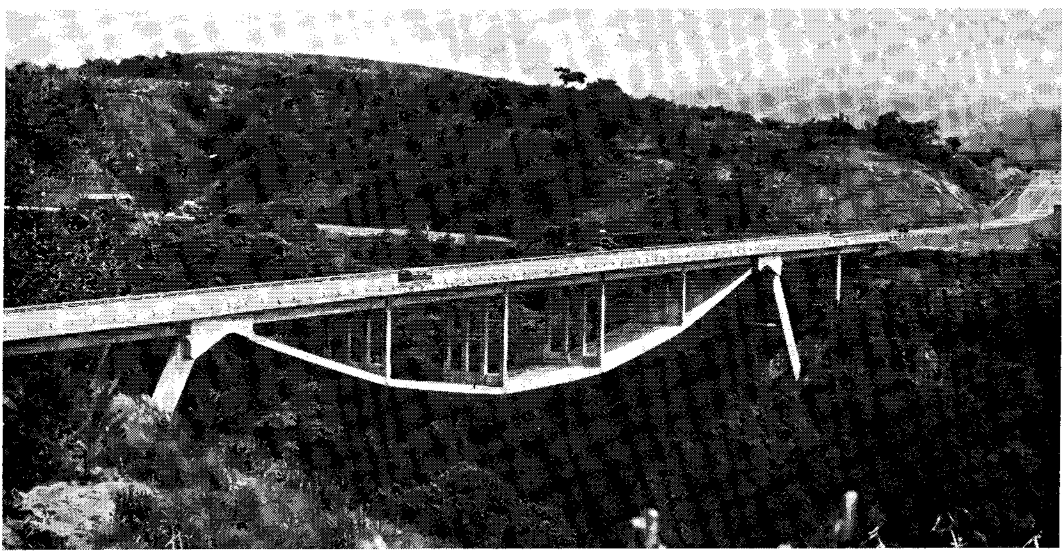


Fig. 13. Rio Colorado Bridge.

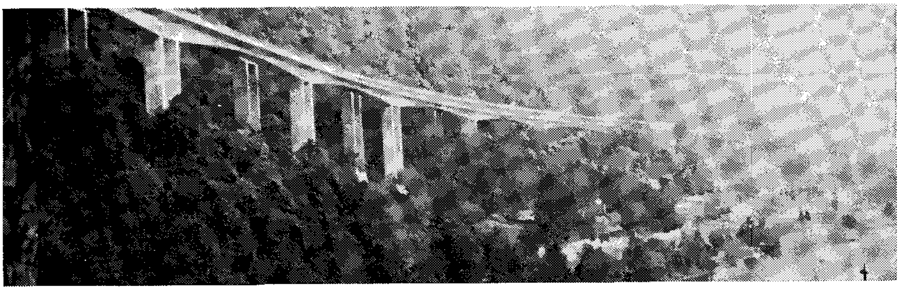


Fig. 14. Chillon Viaduct.

province of suspension bridges. His stress ribbon bridge, conceived at about the same time as the Mangfall design, carried prestressed concrete far beyond its previous limits. He made a design for the Bosporus Bridge which would have had a free span of 454 m (1500 ft).[47]

The Recent Past

Appropriately, the first work will be the 1972 highway bridge over the Rio Colorado (see Fig. 13) in Costa Rica designed by T. Y. Lin International and spanning 145 m (479 ft) between supports over a 91 m (300 ft) deep valley.[48] This new form shows its structural logic clearly in the almost polygonal lower chord, its delicate verticals and its straight light horizontal roadway.

The same sense of form appears in the recent Chillon Viaduct (see Fig. 14) along the northeast shore of Lake Geneva and designed by Prof. **Piguet** of Lausanne. Here the design was chosen after a competition in which the criterion of aesthetics played a major role. The double cantilever method used precast elements post-tensioned together and the total final cost of the 2½-kilometer (1½ miles) viaduct was only $14 per sq ft.[49]

Finally, and departing slightly from the historical focus, is the newest bridge of Switzerland's most talented contemporary bridge designer, **Christian Menn.** It will be on the road going over the Simplon Pass and it reflects the continual search for form in prestressed concrete.

In a way, each of these three recent works are by mature designers who have worked with prestressing since its early days of the 1950's. Thus, they are very like the earlier pioneers whose major contributions came after a long contemplation of structures.

Whether they would admit it or not, the crucial factor was the study of history. Not a study of names and dates, but rather of forms and of full-scale behavior. Ideas in structure come from understanding clearly the works of the recent past; but they also come from abroad as well as from home.

In understanding more clearly the works of Freyssinet, Magnel, and Finsterwalder, American engineers have begun adapting prestressed concrete to American conditions. In so doing, designers like T. Y. Lin, engineers of the state of California, and others have shown how new American forms can become a central part of the recent past that engineers everywhere will need to study.

Freyssinet's difficult years from 1928 to 1935 have led to new forms that have become symbols of how the structural environment of the late 20th century can be built, not only to save materials and money but also to add elegance and dignity equal to any period in mankind's history.

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