TRANSFERRING TECHNOLOGY FROM EUROPE TO AMERICA

Cases in Concrete – Thin Shells and Prestressing

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ANTON TEDESKO AND THIN SHELL CONCRETE STRUCTURES

Rarely can historians attribute to one person the introduction into society of a new and widely useful engineering idea. We have no difficulty, however, in attributing to one structural engineer, Anton Tedesko (1903-1994), the introduction of thin shell concrete roof structures into the United States. This achievement merits some reflection not only on the events themselves, but also on the background and personality of the individual engineer.

European Background

Tedesko studied engineering at the Technological Institute in Vienna, graduating in 1926 with a diploma in Civil Engineering. There he followed the Technische Hochschule tradition typical of central Europe, grounded in systematic structural analysis under Friederich Hartmann, in wide-ranging bridge design using texts like that of Josef Melan, and in practical, thorough exposure to reinforced concrete structures under Rudolf Saliger. One has only to compare the writings of these men to those of comparable professors in the best American engineering schools of the 1 920s to see the major differences. First, Hartmann's clear presentations of basic structural theory was joined with a strong emphasis on the aesthetics of structure, which he published in 1928.' Second, Melan's wide grasp of bridge practice was based primarily on his deep experience in design going back to the very beginning of reinforced concrete in the 1880s.[2] Third, the flamboyant Saliger's immersion in design practice and detailed research led to his systematizing of reinforced concrete as an academic discipline.[3]

The study of bridge design illustrates well Tedesko's schooling where academic engineers wrote about design. Mdrsch in Stuttgart, Melan in Prague, and Hartmann in Vienna wrote pioneering texts in bridge design. All three were professors. In the United States by contrast, the writers of major works on bridge design, David Steinman, Wilbur Watson, J. A. L. Waddell, and Conde McCullough (with E. S. T. Thayer) all were practitioners.[4]

The books themselves are different in focus. For example, Melan in his sections on concrete bridges, surveys bridges throughout the Western world giving structural details and pictures, whereas McCullough and Thayer show only examples of concrete bridges in Oregon where they were practicing. The reader of Melan's work is encouraged to think internationally whereas the reader of McCullough's has only physical examples from one restricted location. In both cases the structural theory is the same; it is primarily in the exposure to completed works in different cultures that the two works differ greatly.

A comparison of textbooks in reinforced concrete also shows the broader compass of the European education. Saliger's book on reinforced concrete is filled with details, drawings, and photos of completed structures, whereas the major new American text of the 1920s, *Design of Concrete Structures* by Urquhart and ORourke (1923), has only one photograph in the entire 452-page book and almost no review of completed structures.[5] Thus, European education, in contrast to the United States, stressed much more both the completed works and the variety of designs found in different countries.

Early Apprenticeship

With this education, the newly graduated Austrian civil engineer arrived at Ellis Island with little except contacts with the Austrian community in Chicago. Anton Tedesko passed through immigration in early May of 1927, walked across the Brooklyn Bridge, and on May 8 took the train to Chicago where his host was an older Viennese engineer, Hans (later John) Kalinka (1889-1967). Within a week Tedesko had a job as a tracer, a low level draftsman, which gave him a small income and a chance to improve his English.[6]

The job lasted 5 months and after 2 months of looking he found another job, this time as a steel detailer. That work lasted one year until in late 1928 he fell ill, went to California to recuperate with friends, and in May 1929 sailed home to Europe. He had learned about American engineering practice, he had developed what were to be long-lasting friendships with American engineers, and he now was fluent in English. He had yet to settle on a career direction but he had developed a strong liking for the United States.[7]

Fig.1 Anton Tedesko

Once back in Vienna, one of his professors, Ernst Melan, hired him as an assistant and urged him to work for a doctors degree leading to an academic career. After six months, however, the young engineer decided on practice over research and went to work with the well-known designer-builders, Dyckerhoff and Widmann in Wiesbaden. There over a two-year period he discovered thin-shell concrete structures by working with a talented group of engineers: Franz Dischinger (1887-1953), Ulrich Finsterwalder (1897-1988), Wilhelm Flügge, and Hubert Rüsch (1903-1979). The first two were designer builders while the last two became academics, Flügge writing a pioneering text on thin shells and Rüsch doing advanced research on reinforced concrete structures.[8]

Fig.2 Large-scale model dome designed by Dischinger

It was an exciting time for Tedesko because these Germans were the first to build thin concrete roof shells on the basis of careful physical model tests and of evolving mathematical theories. Before he arrived Dyckerhoff & Widmann had already designed and built planetarium roofs and market halls in dome and barrel shapes.[9] As Tedesko gained experience with the firm and as the firm gained confidence in his abilities, a new possibility opened up. Thanks to Tedesko's personal relationship with Kalinka, now an engineer in a design-construction firm, Dyckerhoff & Widmann decided to transfer their young Austrian engineer to Chicago to introduce thin shell concrete construction into the United States. Already in the spring of 1931, Tedesko and Kalinka were corresponding about this new idea and in August, Kalinka sent a proposal to Wiesbaden which the German firm accepted on condition that Tedesko be put in charge of the American work for a trial period of one year. The plan was for Tedesko to return to Europe thereafter while an American engineer would be trained in Germany to replace him.[10]

Fig.3 Barrel shell roof in Belgium designed and built by Dyckerhoff and Widmann

The Young Entrepreneur for Concrete Shells

The 28 year old engineer arrived in the Chicago office of Roberts and Schaefer Co. on the 11th floor of the Wrigley Building and immediately began an arduous two years of planning and promoting the new German thin shell roof designs known then as Z-D Shell Roofs (Zeiss-Dywidag). Tedesko traveled widely explaining the ideas to engineers, architects, builders, and owners. He was up against both the deep economic depression and the conservative engineering profession. Tedesko had to confront engineers and owners who were used to more traditional structures and who were not used to the analysis of such seemingly complex shapes.

The Century of Progress World's Fair in Chicago provided the first success for Tedesko's efforts in the unlikely form of a thin shell roof for the Brook Hill Dairy Exhibit during 1933-34. Tedesko had to convince the Milwaukee architect and the Starline Inc. design-build firm to accept the pioneering design (for the United States) which the latter firm advertised as providing "These cows [with] comfort and safety greater than that ever before enjoyed by any cows anywhere" in a building that "cannot burn, rust, rot, or blow away." The visitor could see 30 cows producing milk at the exhibit but few recognized the object of the cows' enjoyment - the thin barrel roof covering in concrete.[11]

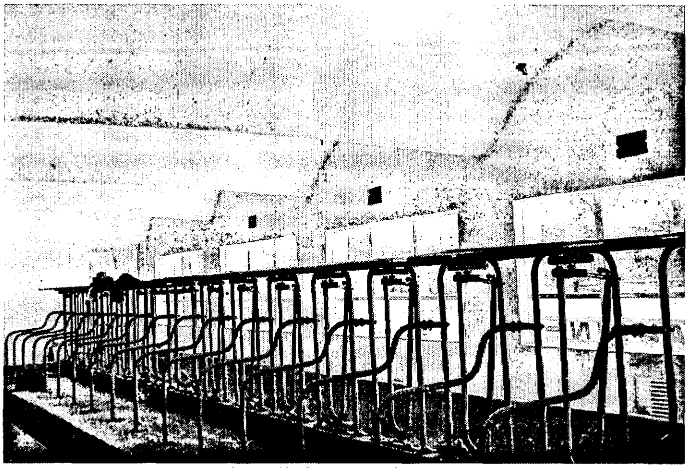

Fig. 4 Brook Hill dairy building in Chicago

But this structure was more than a cow cover, it was also an engineers' experiment. Whereas the "public will see [Vitamin D milk] as it passes from cow to bottle" the profession saw in a full-scale load test the roof pass from visual object to scientific stresses. These latter were low enough to permit positive evaluations by important engineers represented at the load tests by people from the Portland Cement Association (an arm of the cement manufacturers in the USA), and by engineers from the University of Illinois as well as representatives of Roberts & Schaefer Co.[12] This visual and technical demonstration was essential but it did not cause the rush to shells that Tedesko had hoped. Rather continual travels, meetings, and preliminary designs did produce a few projects that led to the decision that Tedesko remain in the United States and even become an employee of Roberts & Schaefer Co.

New Shells 1934-1936

By 1934 Tedesko had become familiar enough with American practice to write an article for the German Journal *Bautechnik* on the use of concrete in North America.[13] He had studied the American literature, become friends with academics and professionals, and observed numerous construction sites. He had a self-defined graduate education which would become essential to the challenges awaiting him.

The first completed American concrete dome, begun in 1934, was for the roof of the Hayden Planetarium building built for the American Museum of Natural History in New York City (between 77th and 81st streets along Central Park West in Manhattan). Tedesko had to convince the architects and the structural engineers of the successful experience in Germany and of the safety and relative economy of the 80 ft. - 6 inch diameter concrete hemisphere of only 3 inches in thickness.[14]

There had already been Planetaria in Philadelphia and Chicago and one was under construction in Los Angeles. New York was behind and eager to have this new means of projecting the images of celestial bodies moving through their courses. The Carl Zeiss optical firm had originally stimulated thin concrete shell design by deciding in 1922 to construct such a dome in Jena to test the functioning of their new planetarium to be placed in the German Museum in Munich. They collaborated with Dyckerhoff & Widmann who built the dome and whose engineer Dischinger began then to develop a mathematical theory for such shells.[15] Hence the name Zeiss-Dywdag System.

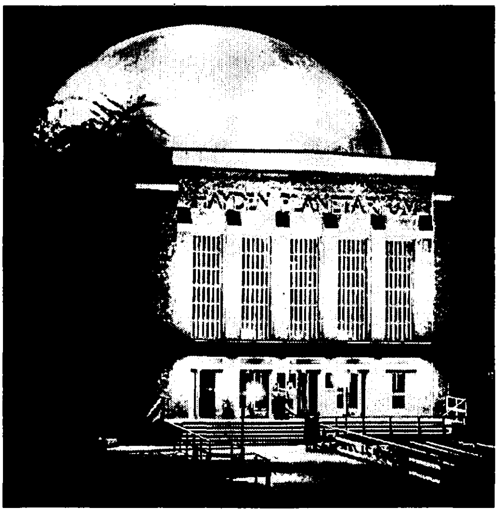

Fig.5 Hayden Planetarium in New York City

By 1935 Tedesko had professional friends in many cities, some were official Roberts & Schaefer representatives, others were employees of the Portland Cement Association, and still others were architects, engineers, or builders. In Philadelphia, the company's representative helped Tedesko develop a relationship with America's leading entrepreneur of chocolate, Milton Hershey (1857-1945). Also helpful as an early contact was a Philadelphia engineer representing the Portland Cement Association. They gave Tedesko the chance to present his ideas for a large sports palace mainly for ice hockey to the Hershey people, in particular Paul Witmer, vice president and manager of Hershey Lumber Products.[16]

On January 21, 1936 Tedesko gave Witmer a proposal for designing the shell roof and the Hershey Company agreed. Tedesko hired staff in Chicago, design work started immediately, and on February 7 he began to write out in detail the full calculations for the roof structure. He completed the 63 pages by February 28 and ground was broken on March 11 to begin work for the foundations. The Hershey Company pursued the project in the highiy unusual way of using its own chocolate workers for the construction crew.[17]

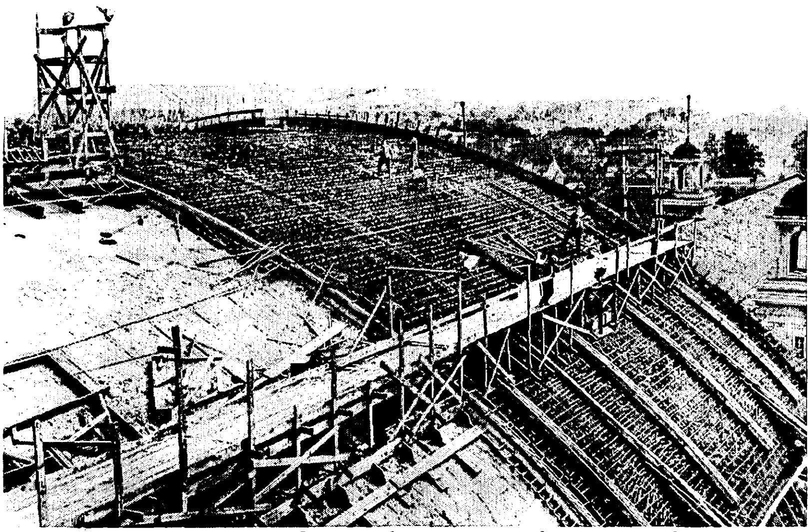

Fig. 6 Roof of Hershey Arena under construction

Hershey had begun to build his company town in 1903; the factory became the largest chocolate manufacturing plant in the world. During the 1930s he built a community center, the Hershey Inn, and the new sports arena which would be the largest single-span concrete roof in America: 232 ft. wide and 340 ft. long with a shell thickness of only 3-1/2 inches. For Tedesko this was "the most satisfying challenge of the 1930s... The engineering and construction decisions were mine. No codes existed that would apply to this work. No rules had to be followed. I shaped and calculated the structure according to my best judgment, influenced by what I had learned in Wiesbaden under Dischinger and my good friend Ulrich Finsterwalder."[18]

The Hershey Arena gave Tedesko a unique chance to develop independent judgment and self confidence. "In Europe, such a structure would have been designed under the guidance of professors. Had I remained in Europe, there never would have been a Hershey-type opportunity for me. In Europe, there would not have been only a single person in charge of such a project, and certainly not someone 32 years old." So did Tedesko reflect upon that experience *50* years later.

Naturally, with so much riding on the success of the Hershey Sports Arena, the initial deflections of the structure due to creep worried Tedesko, and were exacerbated by the rumors about the 1933 Cottbus Hangar designed by Finsterwalder which collapsed several months after it had been built.[19] The Hershey Arena shell was supported on substantial stiffening ribs, the lack of which had led to failure at Cottbus, and Dyckerhoff & Widmann sent a graph of deflections over time from four other such structures which had stopped deflecting altogether after their initial creep. Such hard data consistently reproduced in field tests was of inestimable value to Tedesko in his further pursuit of thin shell construction in the United States; it enabled him eventually to design hangars of unprecedented size in Rapid City, SD and Limestone, ME after World War II.

During the Hershey construction visitors came, especially prominent engineers and builders, some of whom would become close friends of Tedesko and help him get future projects. One was Lieutenant Commander Ben Moreell who would later become a full Admiral and a

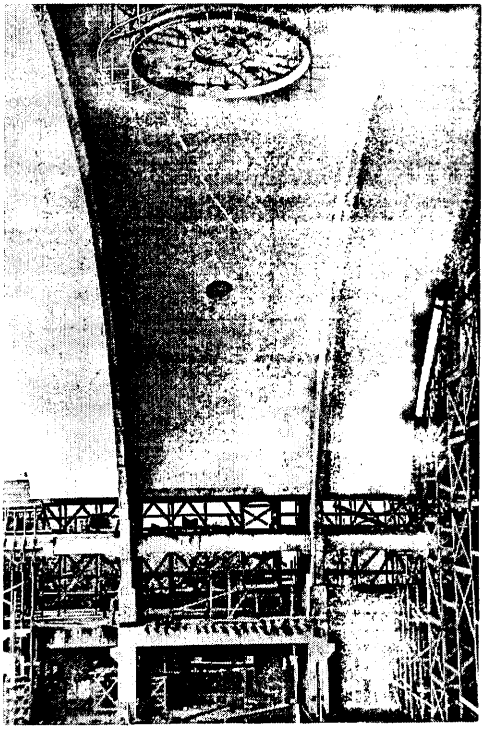

Fig.7 Inside of the Hershey Arena during construction

right-hand man to President Roosevelt during the war. Tedesko got many navy hangar designs through Moreell's help based at first upon the impressive chocolate arena.

Technology Transfer: Tedesko the Austrian American

The American acceptance of thin shell roofs picked up and in 1937 and 1938 with a series of designs that built largely on the success at Hershey. Three of these shell roofs characterize Tedesko's mastery of diverse forms and of fitting them to American conditions: The ached Hershey-like roof shell for the Philadelphia Skating Club and Humane Society in Ardmore, the two dome roofs covering trickling filters in

Hibbing, Minnesota, and the long, multiple-barrel (Brook Farm-type) roof for the Armstrong tire factory at Natchez, Mississippi.

Domes, however challenging for design, are rarely used because of the circular ground plan whereas barrels fit the more common rectangular plans, such as that for industrial buildings, the largest of the early shells by Tedesko being the tire factory roof at Natchez. Covering 121,600 sq. ft. this substantial work proved that the German ideas for industrial economy could transfer to the United States. Comparative studies of more standard structural types showed that the concrete shell was competitive and also reduced fire hazard. The main structure was made of circular shells 40 ft. wide and spanning 50 ft. These act like 50 ft. long beams whose cross section is the thin curved slab 40 ft. wide. Tedesko calculated the maximum compressive stresses in this shell to be less than 10% of the compression capacity of the concrete. Typical for most shells, these results illustrated that the thinness does not compromise safety.[20]

By 1939 with these and a number of other contracts in various stages of development, Tedesko had succeeded in proving the value of this new type of roof structure in the United States. He had operated as an entrepreneur in designing, testing, selling, and publicizing the new forms that he had brought from Europe and that he had begun to modify for American practice. His largest works were yet to come and he would only reach international fame years later, but the essential transfer of a new technology had taken place in those depression years between 1932 and 1939, or more properly between the two World's Fairs: The Century of Progress 1933-34 and the World of Tomorrow 1939-40. Following World War II, a second major case of technology transfer would take place, this one stimulated in large part by a Belgian professor of structural engineering.

GUSTAVE MAGNEL AND PRESTRESSED CONCRETE STRUCTURES

On April 20, 1949 Philadelphia officials broke ground by the Wissahickon Creek in Fairmont Park for the Walnut Lane Bridge. The design for this 160 foot span bridge "follows that developed in Belgium by Professor Gustave Magnel, M. ASCE, of the University of Ghent." It was the first bridge of its type in the United States to be built of a European innovation, prestressed concrete.[21] Like Tedesko with thin shells, Magnel (1889-1955) was the principal figure in bringing a European idea into American practice. Like Tedesko, Magnel was not the originator of prestressing that person was Eugene Freyssinet (1879-1962) whose 1928 patent first showed how prestressed concrete could be a reliable material for large-scale structures.[22] But Magnel like Tedesko was a skilled apologist and grasped fully the technical basis for design. Both men had command of the English language and wrote for an English-speaking professional audience.

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.[23]

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.[24] 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 war years 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.

Fig.8 Gustave Magnel

He had already written at least nine books, some of which had gone through three editions when, in 1948, he wrote *LeB~ton Pdcontraint* which was soon translated and published in English, went through three British editions and was also later published in the United States.[25] 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:[26]

> 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.

Fig. 9 Large-scale beam in Magnel's laboratory at Ghent University

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.

Magnet and the Sclayn Bridge

Through the Belgium American Foundation, Magnel had visited the United States in 1947 and lectured widely on prestressed concrete structures. By then he had already carried out substantial research in his laboratory and applied his results to a growing number of designs for buildings and bridges in Belgium.[27] But the most impressive work was to begin the next year at the small town of Sclayn on the Meuse River near Namur.

The Belgian Bridge and Highway Administration held a design construction competition in 1948 for a bridge to be built at the location of one destroyed in World War II. The Administration had made a design of two 62.7 meter (206 feet) steel truss spans and invited alternates in steel, reinforced concrete, or prestressed concrete. The bids for steel were all high with one reinforced concrete arch design the least expensive. The jury chose the second lowest bid, a continuous two-span prestressed concrete hollow-box structure submitted by the builder Blaton-Aubert and designed by Alexandre Birguer. The chief engineer of the Administration considered the bridge "indisputably the most elegant design from the point of view both of aesthetics and technique"[28]

Professor Magnel had been a consultant for the design and had developed the prestressing system which Blaton had patented. Magnel presented the detailed calculations for this pioneering work in his 1948 book on prestressed concrete.

Fig. 10 Sclayn Bridge over the Meuse River in Belgium

The Sclayn Bridge represented a kind of summation of his ideas up the Walnut Lane Bridge. Indeed once the builders began to work on that American structure, a group of six engineers and contractors associated with the bridge travelled to Europe to study prestressing there: the central work they saw was the bridge at Sclayn then well along in construction.[29]

Of special significance was Magnel's idea that the bridge should also be a laboratory where the performance of the bridge in service could be monitored continuously over time. Since prestressed concrete was so new, many engineers were worried about the loss of prestressing force and Magnel designed a laboratory inside a hollow box where engineers could record stresses in exposed wires as well as in the concrete structure. Carefully measured results demonstrated the validity of Magnel's calcuations and predictions and helped give engineers confidence in the innovation.[30] All of this design and planning lay behind Magnel's reception in the United States in the late 1940s.

Fig.11 Portrait of Gustave Magnel with picture of the Sclayn Bridge above

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 below the engineers estimate: "It is also quite possible that this First Conference on Prestressed Concrete might not now be in session.."[31]

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 1947 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. Here the Art Jury objected to the mass of an unfaced arch. The second solution suggested itself almost by accident.[32]

> 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. B. 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. Coti, Consulting Engineer of New York, and representatives of the Preload Corporation. Contracts were also made with Professor Gustave Magnel in Belgium.

Charles C. Zollman a former student of Magnel's at Ghent and then an employee of the Preload Corporation, made early contact and eventually translated Magnel's book on prestressed concrete into English. 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 historically significant events in the relationship between structure and aesthetics.[33]

Fig 12 Zollman, Magnel and Baxter at the Walnut Lane Bridge

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.

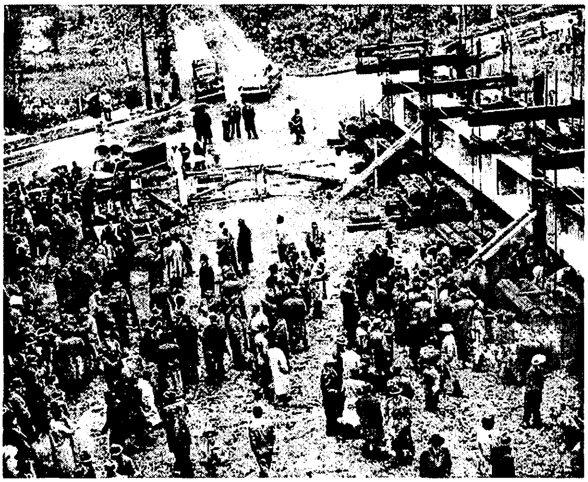

Fig. 13 Test to destruction of one beam at Walnut Lane Bridge.

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 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.

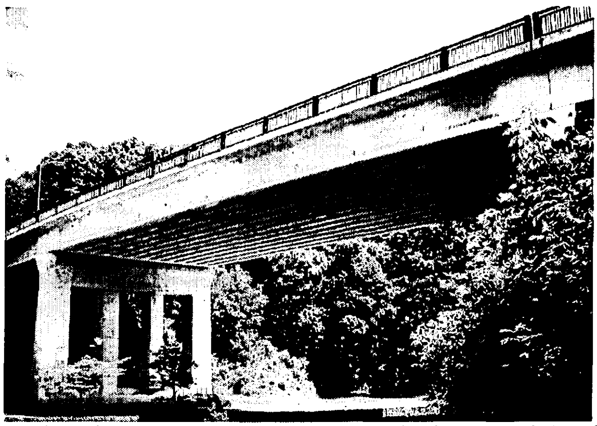

Fig.14 Completed Walnut Lane Bridge over Wissahickon Creek in Philadelphia

Another feature of this bridge was the full-scale test to destruction of one of its 160-ft long girders. Perhaps unnecessary in principle, this test did serve dramatically to demonstrate, in practice, and in front of at least 500 engineers, the high overload capacity of the bridge built along these lines.

Typical of Magnel, he designed, organized and directed the load test which he then described in full numerical detail in the second edition of his text book. His careful planning and interpretation of the results helped convince American engineers of the reliability of calculations and the inherent safety of prestressed concrete.[34]

Unlike Tedesko, Magnel did not immigrate to the United States, but remained at Ghent until his death in 1955. His influence came through writings, through the Walnut Lane Bridge, and through visits to the United States. Had he lived to attend the 1957 World Conference on

Fig. 15 T.Y. Lin, on the cover of *the PCI Journal* Sept/Oct 1976, spent a year in Magnel's laboratory in the early 1950s

Prestressing in Berkeley, he would have been honored as a central figure in the transfer of prestressing to the United States. The leader of that conference was Berkeley professor T.Y. Lin, who had spent a year in Magnel's laboratory in the early 1950s. So Magnel's influence propagated across the country. Professor Lin became the leading academic promoter of prestressed concrete in the United States, eventually founding his own design company as well.

Personal Reflections on Magnel and Tedesko

Magnel also had an influence on bringing prestressed concrete to the United States through his impressive teaching to a small group of Americans in the early 1950s. I was fortunate to be one of the first to benefit. In 1950 I won a Fulbright fellowship for study of bridge rebuilding in Belgium and of structural engineering at the University of

Louvain. M. Roger Fougnies, Ing~nieur en chef-directeur des Ponts et Chauss6es, took me one day a week to visit bridges under construction or recently completed. It was a field education and the most impressive time was our trip to Sclayn where we climbed into the hollow-box laboratory of Magnel's.

Then one day M. Fougnies took me to Ghent to meet Professor Magnel himself. Following that visit, in the spring of 1951 Magnel gave in French an evening course on prestressed concrete and the Walloon section at Louvain took me along. Once a week we would drive from Louvain to Ghent and there I came to know the famous professor. Since Louvain was then bilingual I had begun to take courses there in both French and Flemish so that I was able to apply for a renewal of my fellowship in order to study with Professor Magnel at Ghent.

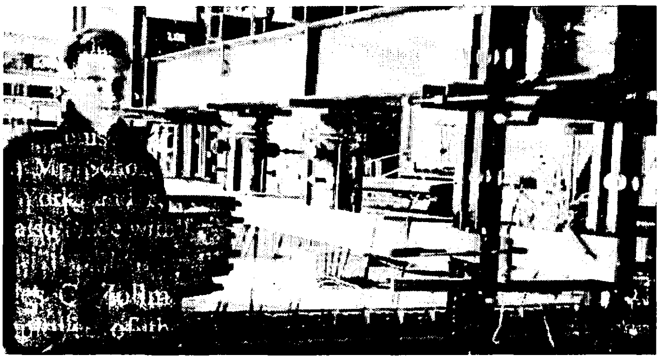

Fig. 16 Fulbright student David Billington in the Magnel laboratory, 1952

Thus in the fall of 1951 my wife and I, newly married (she was also a Fulbright fellow studying piano at the Royal Conservatory in Brussels), settled into our honeymoon carriage house in Ghent. There I spent a highly stimulating year following Magnel's lively courses, studying prestressed concrete design, and carrying out research under the professor's direction. We met every week to discuss the research on full-scale prestressed concrete beams and I absorbed his teaching which, in spite of my elementary Flemish, was elegantly clear. I would describe his ideas to my artist wife and I knew Magnel's clarity was catching when I heard her explain the principles of prestressing to our humanist friends in Ghent.

Thanks to this unusual education I was able to get a good structural engineering job when we returned to the United States in the fall of 1952; but more to the point, once at work I found that my employer was open to trying out some designs using prestressing. Thus between 1952 and 1955 I was able to design a number of prestressed concrete structures, following Magnel's ideas, and the most supportive of these new works was the vice president of our company, Anton Tedesko. So it was that after leaving Magnel I had met Tedesko in Chicago and heard his speech on thin shells at the Centennial Convention of the American Society of Civil Engineers. He introduced me to the head of the New York office of Roberts & Schaefer Co. who offered me the job.

While designing prestressed structures I was also exposed to thin shell concrete design and would frequently visit sites with Tedesko. Gradually his pioneering work made a deep impression as did his wide ranging knowledge of structural engineering. Whereas Magnel was a great educator, Tedesko was a great practitioner, But both had the highest quality in engineering, that of understanding how structures performed under loading. Neither were afraid of mathematical analysis but neither were seduced by it; they sought to simplify and were led always by observations either of large-scale tests or of structures in service.

Close personal experience with these two pioneers in transfer of major engineering from Europe to the United States has more and more convinced me of the necessity to study and teach about the grand tradition of modern engineering. Central to that tradition are a few primary people who saw the possibilities for innovation and who succeeded in leaving a legacy of accomplishment that can help to guide us all into the future.

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[15] DISCHINGER, F., "Schalen and Rippenknppeln," Chapter II, Vol. 12, 3rd Ed., *Handbuch fUr Eisenbetonbau,* Berlin, 1928, pages 151-371.

[16] ANTON TEDESKO, *Chronicle IM* pp. 25-29. See D. Paul Witmer "Sports Palace for Chocolate Town" and Anton Tedesko, "Z-D Shell Roof at Hershey", *Architectural Concrete,* Portland Cement Assoc., Vol. 3, No. 1(1937): pages 1-11. Also "Thin-Shell Barrel Roof, *Construction,* April 1937, pages 44-47 and Anton Tedesko, "Large Concrete Shell Roof Covers Ice Arena", *Engineering News Record,* April 8, 1937.

[17] In February of 1981 Tedesko put together these calculations to send to Hershey and a copy is deposited in the Tedesko papers at the Princeton Maillart Archive.

[18] TEDESKO, *Chronicle IV*, the stories connected with the Hershey arena appear in pages. 25-29.

[19] ANTON TEDESKO, "A Few Structural Case Studies," talk given at ACI Safety Symposium, Boston, April 1975.

[20] ANTON TEDESKO, "Tire Factory at Natchez", *Engineering News-Record,* October 26, 1939. The compression stress given was 282 psi and the concrete strength at decentering was 2500 psi such that after a few weeks the strength would be at least 3000 psi.

[21] E.R.SCHOFIELD, "Construction Starts on Prestressed Concrete Bridge in Philadelphia" *Civil Engineering,* July 1949, pages 32-34.

[22] DAVID P. BILLINGTON, "Historical Persepective on Prestressed Concrete", *Journal of the Prestressed Concrete Institute,* Vol 21, No. 5, Sept-Oct. 1976

[23] EVANS, R. H., "Speech," *In Memoriam Gustave Magnel,* October 1956, p. *51.*

[24] ANSEELE, E., "Speech," *Ibid.* p. 31.

[25] MAGNEL, GUSTAVE, *Prestressed Concrete,* Third Edition, London, 1954.

[26] MAGNEL, *op. cit.,* p. 84.

[27] CHARLES C. ZOLLMAN, "Magnel's Impact on the Advent Of Prestressed Concrete", *Journal Prestressed Concrete Institute,* May/June 1978, pp 22-48.

[28] ERWIN STORRER, "Innauguration du pont en baton pr6contriant sur la Meuse, A Sclayn", *Annales des Travaux Publics de Belgique,* V 103, April 1950, pp 173-196.

[29] E.R. SCHOFIELD, "Prestressed Concrete Used for Boldly Designed Structures in Europe", *Civil Engineering,* Sept. 1949, pp 22-27, 92.

[30] E. DEHAN and M. LOUIS, "Mesure des efforts, et de leur variation, dans les fils accessibles des ouvrages en baton pr6contraint. Application au Pont de Sclayn," *Annales,* op.cit.,pp 201-256.

[31] BAXTER, S. S., and BAROFSKY, M., "Construction of the Walnut Lane Bridge,": *Proceedings, First United States Conference on Prestressed Concrete,* Massachusetts Institute of Technology, Cambridge, August 1951, p. 47.

[32] *Ibid,* pp. 47-48. According to M. Fornerod, then Chief Engineer for Preload, it was one of his engineers, Charles Zollman, later one of the organizers of the Berkeley Conference, who suggested Magnel. Zollman had been a student of Magnel's at Ghent and had helped him with the English language version of his book.

[33] *Ibid,p.48.*

[34] ANDERSON, A.R., "Field Testing of Prestressed Concrete Structures," *Proceedings, First United States Conference on Prestressed Concrete,* Massachusetts Institute of Technology, Cambridge, August 1951, pp. 2 15-217. The test was described by G. Magnel in "Prototype Prestressed Beam Justifies Walnut Lane Bridge," *ACI Journal,* Proceedings V. 47, December 1950, pp. 301-3 16; and by M. Fornerod in the *Bulletin* of the IABSE, Zurich, 1950; it also appears in detail in Magnel's book, *op. cit.,pp.* 188-200

[35] GUSTAVE MAGNEL, *Prestressed Concrete,* second edition. London, 1950, pp 154-165.