Reflections on the Beginnings of Prestressed Concrete in America

Nineteen seventy-nine is the 25-year Silver Jubilee of the founding of the Prestressed Concrete Institute.

To commemorate this important anniversary, the PCI JOURNAL is presenting a series of papers on the early history of prestressed and precast concrete in North America. These papers are being narrated by the persons who participated in the early development of the industry and are based on their experiences and recollections.

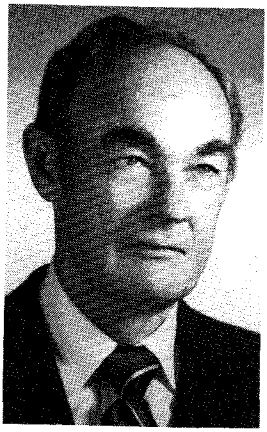
Part 1 traced the events that led to the construction of the Walnut Lane Bridge and particularly the significant role that Professor Magnel played in introducing prestressed concrete to America. Part 2 covered the major accomplishments American engineers made in launching the prestressed concrete industry. Part 3 described the beginnings of the pretensioning industry in Florida.

In Part 4 (appearing in this issue) Ross Bryan recounts the building in Tennessee of some of the earliest linear prestressed concrete structures in the United States.

We believe that these series of articles will not only be interesting to read but will serve as an historical record of one of the most exciting periods in the annals of construction.

Part 4

Prestressed Concrete Innovations in Tennessee



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Individual precast prestressed members must be integrated into a structure so that upon completion it has the appearance and structural integrity of a monolithic structure.

Quietly and independently, away from the main hub of construction, some innovative ideas were being implemented with prestressed concrete deep in the State of Tennessee.

This work involved the construction of the first linear prestressed concrete structures (using machine-made block beams) built in the United States, the introduction of continuity in prestressed spans, the first use of deflected strands in pretensioned beams as well as other design and construction innovations.

This paper will describe these developments in some detail and close by discussing some recent research work which might hold promise for the future.

Introduction

I had no knowledge of European developments in prestressed concrete until after World War II, when this work was described by several authors in the technical literature and some engineers returning from the war areas. I did, however, have knowledge of some attempts at structural precasting that had been

Based on his personal experiences, the author describes some innovative uses of prestressed concrete in Tennessee. He recounts the building of the first linear prestressed concrete structures in the United States, the development and use of deflected strand and the introduction of continuous construction.

made in the United States and I became very interested in them—so interested that upon returning from the service I applied to the leading fabricator for a job. I received a polite rejection but this did not dampen my enthusiasm. When I finally became aware of the weight that could be saved by prestressing, I began to think about ways to apply this advantage to precast systems.

Prestressed concrete became a reality in Tennessee when the newly formed consulting firm of Bryan and Dozier began an informal relationship with the Nashville Breeko Block Company in January of 1950, which resulted in the construction of the Fayetteville Stadium and the Madison County Bridge. This relationship would continue for a decade with neither party feeling the necessity of a formal or written agreement.

During this period hundreds of structures were built and many fabricating procedures were developed. Some procedures were improved, some discarded, and some, which were accepted by the industry, are still in use today. It was a relationship in which each party contributed time and/or materials as required to develop a new and exciting method of construction.

Carroll Strohm was General Manager of the Breeko plant, and his willingness to risk his company's money and reputation in the production of an untried structural product gives testimony to his courage and foresight. The same is true of Ed Rodgers, the young Madison County bridge engineer, and Charles Lindsey, the high school coach at Fayetteville, both of whom literally built their structures with their own hands.

The decade of the fifties was an exciting time for engineers, especially young consultants who were not yet established and had more to gain than lose in the event they chose to develop design and construction skills that older, more established firms preferred to leave to others. It was a time when a designer could establish, in fact had to establish, his own criteria based upon his knowledge and experience—because there were no codes to rely upon.

There were design and construction conferences sponsored by various universities and highway departments during this period. These meetings were usually staffed by the same small nucleus of engineers who at the time were actively engaged in prestressed concrete design. It was a small group with a mutual interest and after the scheduled

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Ross H. Bryan is the founder of Ross H. Bryan Inc., Consulting Engineers, of Nashville, Tennessee. Mr. Bryan designed the first linear prestressed structures to be completed in the United States. He also designed the first structures using deflected, pretensioned strands and developed design procedures for establishing continuity in precast, pretensioned concrete members through the use of mild reinforcing steel.

Mr. Bryan was a member of the PCI Board of Directors in 1959-1960, and Chairman of PCI's Technical Activities Committee from 1960 to 1962. He served as a member of the Fire Test Committee, the PCI Code Committee, the ACI-ASCE Joint Committee on Prestressed Concrete, and the ACI Building Code Committee. Since 1967 his firm has been the inspection agency for PCI's Plant Certification Program.

The author received a BS Degree in Civil Engineering from the University of Kansas in 1933, was employed by the Kansas Highway Bridge Department until 1939, and by the Panama Canal Department until 1942. During World War II he served in the Civil Engineering Corps of the U.S. Navy in the South Pacific.

The firm of Bryan & Dozier was established in 1949 and dissolved in 1952 when each partner set up a private practice. Mr. Bryan then served as president of his firm until his retirement 3 years ago. Currently, he acts as consultant to the firm.

meetings the nights were long and there were many brain-storming sessions. Eventually we would have a code, but this did not come easily. After a number of years a code covering prestressed concrete would be adopted by ACI, but that is another story.

The successful development of a design and construction technique requires input from both field and plant to supplement and confirm the engineering concepts. We were fortunate to have at the Breeko plant two men who shared our enthusiasm for the future of prestressed concrete. Charley Scott was in charge of the prestressing operation, and field problems, of which there were many. Lloyd Markham was the superintendent of the fabricating plant. Both of these men played a significant part in the development of prestressed concrete in Tennessee. Both men are now well known in the industry through their association with Southern Prestressed Concrete Inc. of Pensacola, Florida.

Other authors have described in detail the European contribution to American prestressed concrete design and construction procedures. It is important to remember that the one item required to make prestressed concrete economical in the United States was the production of a high quality tendon that could be bonded without expensive end anchorages. This tendon was developed by Charles Sunderland of the Roebling Company.

To those of us designing in prestressed concrete in the early fifties the Roebling Company was personified by their Sales Manager, Nelson Hicks, and by H. Kent Preston, an engineer assigned to the prestressing strand division. These men played a major role in providing the emerging industry with the research and materials needed to develop new designs and products. They were also very effective in the promotion of prestressed products with clients beyond the reach of most of us.

For several years the Roebling Com-

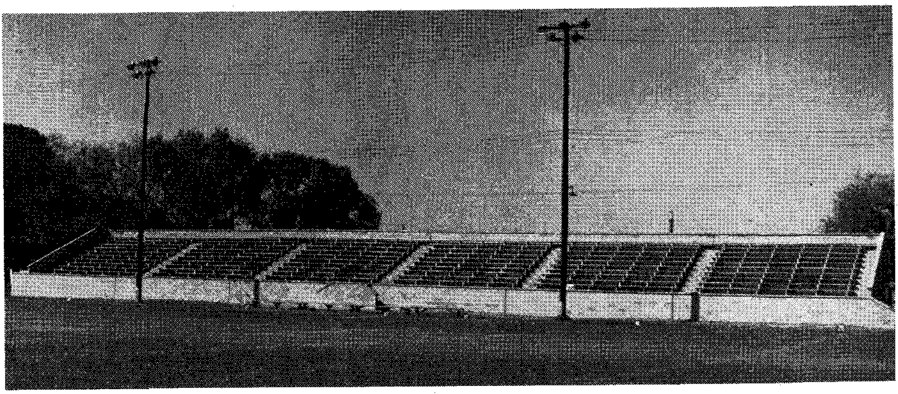

Fig. 1. Fayetteville Stadium, Nashville, Tennessee.

pany was the only supplier of prestressing strand in the United States. It is indeed unfortunate that the company, which performed the pioneering developmental work on prestressing steel has ceased producing strand.

The Portland Cement Association was very active in promoting prestressed concrete. Their field engineers were well trained and had access to most engineers' and architects' offices. In Tennessee, Henry Dougherty of the PCA office in Memphis became interested in the work we were doing, and was responsible for bringing Ed Rodgers, the County Engineer of Madison County, to our office. This contact resulted in the construction of the first prestressed bridge to be built in the United States of wholly American design and construction procedures.

Fayetteville Stadium

The Madison County Bridge was not the first linear prestressed structure to be built in the United States. The first structure was the Fayetteville Stadium, built on the site by local labor and supervised by the High School Coach, Charles Lindsey. We built a small wooden scale model of the stadium and exhibited it in a number of high schools in the surrounding area.

There was sufficient interest to justify the design and construction of a full scale bleacher section at the Breeko plant. On June 24, 1950, Charles Lindsey viewed the bleacher model at Breeko and on July 13, 1950, we received the go-ahead on the Fayetteville Stadium. On August 28, 1950, construction was begun and the stadium was completed on October 29, 1950. The structure is still in use today (see Fig. 1).

The Fayetteville Stadium was built of post-tensioned concrete block beams spanning 30 ft (9.2 m) between masonry piers. The beam units were three core, 16 x 12 x 8 in. (405 x 305 x 203 mm). Specified strength was 3750 psi (25.8 MPa). The tendons were 0.600 in. (15 mm) diameter galvanized bridge strands, tensioned to 26 kips (116 kN) each. The tendons were not grouted (see Fig. 2). The tendons cost $14.00 each delivered in Nashville. The completed stadium cost was $7.65 per seat.

Madison County Bridge

We received the go-ahead on the design of the Madison County Bridge on August 2, 1950. Construction of the beams was begun at the Madison County Highway yard on September 19, 1950. The bridge was completed on October 25, 1950. The bridge beams

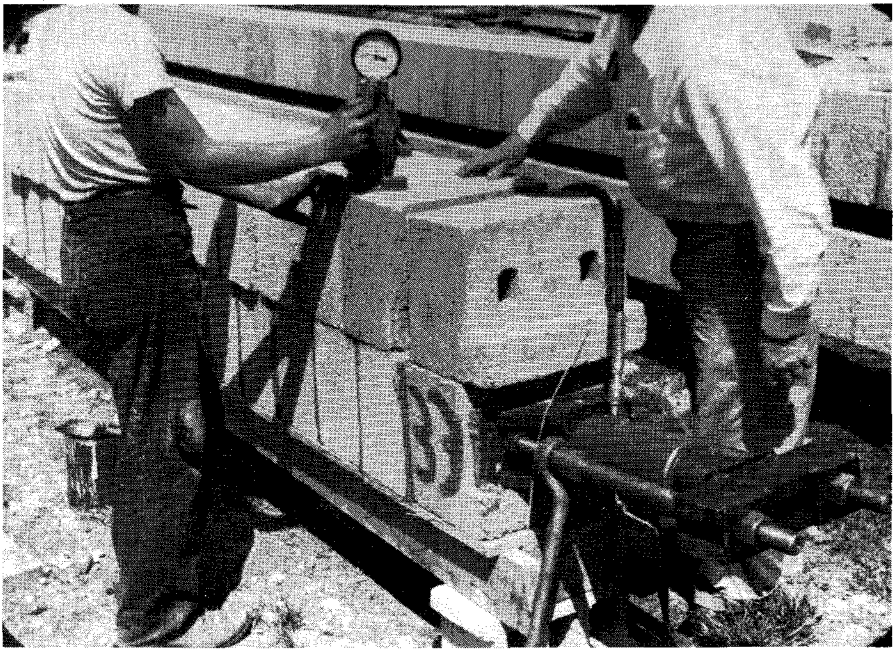

Fig. 2. Tensioning stadium beams.


Fig. 3. Setting Madison County Bridge beams.

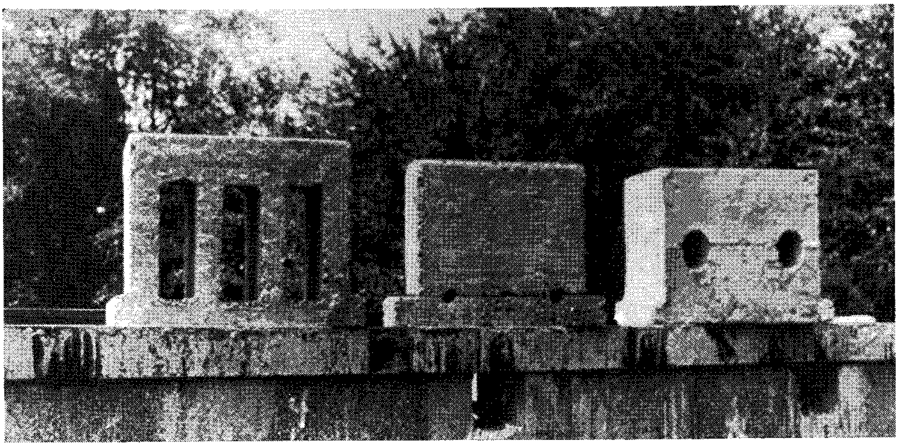

Fig. 4. Madison County Bridge beam units.

were made from the same units as the stadium except the sides of the unit were brought in to form a keyway when the composite slab was placed.[1]

In both the stadium and the bridge, the cores were offset to provide a thickened top flange. The beams were tensioned with the same tendons used on the stadium and were ungrouted. The bridge (see Figs. 3 and 4) is still in service today.

The beam units used in the Madison County Bridge were redesigned for subsequent structures to permit the bonding of the strands and the elimination of fittings at one end by wrapping the tendons around a grooved, reinforced end block.[2] This reduced the cost and increased the ultimate moment capacity of the beams.[3] The new unit also provided a more positive keyway for the distribution of wheel loads (see Figs. 5 and 6).

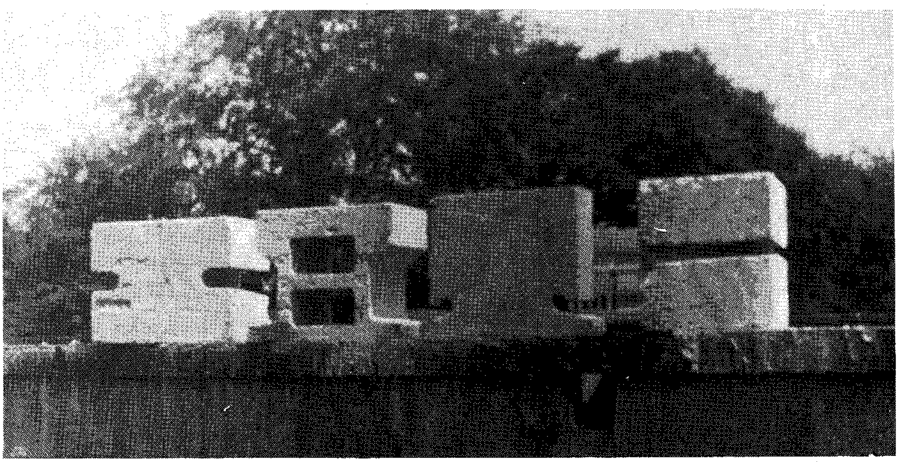

Fig. 5. Redesigned bridge beam units.

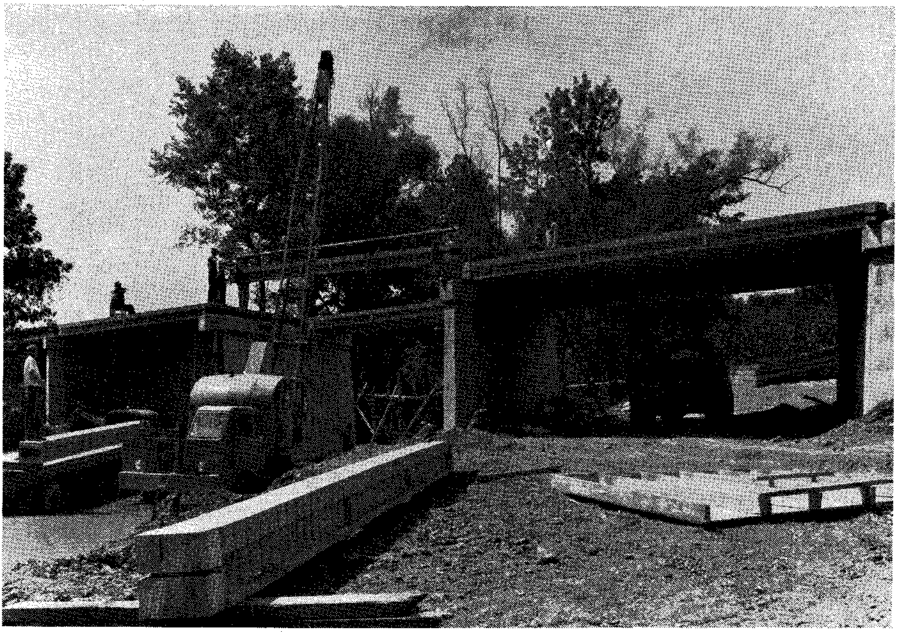

Fig. 6. Bridge beams with bonded wraparound tendons.

Continuous Construction

Beginning early in 1953 all multiple span bridges were made continuous for live load by placing mild reinforcing steel in the topping slab over the interior supports. This also prevented movement of the beams on their supports, which were usually pile bents. Over a period of approximately 5 years more than 50 bridges of this type were built in various parts of the United States and all are still in service today as far as we can determine.

In the early fifties the precast structural systems in general use on buildings included Flexicore, Dox Blocks, and the F&A system. The first two systems used beams, laid side by side, made up of concrete block units reinforced with mild steel bars placed in grooves or in the block cores and grouted to establish bond. The F&A system used precast concrete joists, spaced at 21-in. (53 mm) centers, supporting a machine-made concrete block filler. A concrete topping, which was cast over this assembly, acted compositely with the precast joist. We attempted to duplicate these systems using prestressed concrete block units.

The first prestressed building floor slab was in the Kroger Store in Nashville. The slab span was 20 ft (6.1 m) and the slabs were supported on post-tensioned, cast-in-place girders, continuous over two 45-ft (13.7 m) spans. The girders were post-tensioned with twelve 1-in. (25.4 mm) diameter bridge strands. The strands were greased and wrapped.

This was the first attempt at continuous construction and we had some problems. It became necessary, due to friction, to tension the tendons from both ends and provisions had been made to tension at only one end. It was finally accomplished after making some special fittings.

The beams spanning between the girders were made of 16 x 8-in. (406 x 203 mm) block units and were prestressed

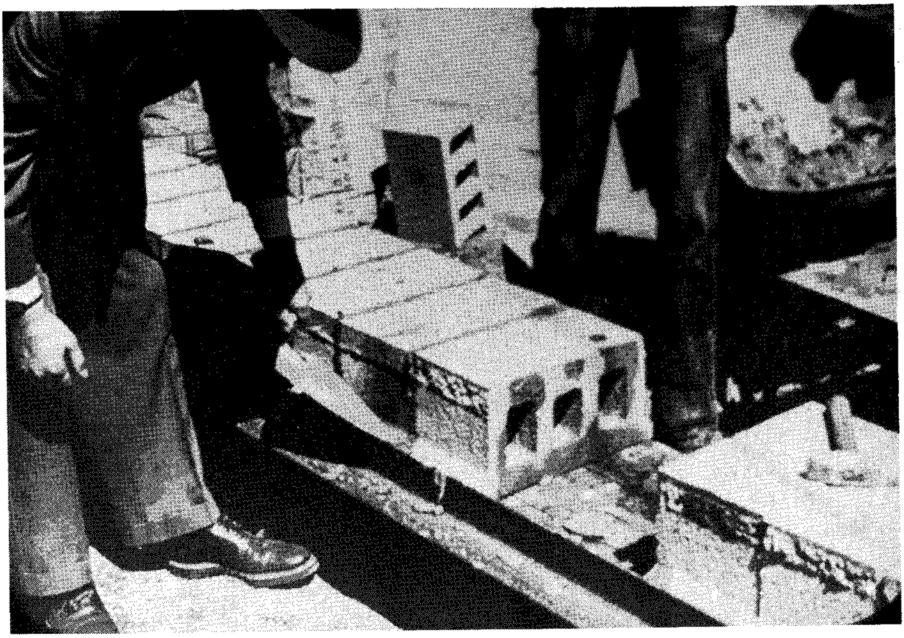

Fig. 7. Fabricating 8-in. (203 mm) block building beam.

with one 0.600-in. (15 mm) diameter galvanized bridge cable in the center core. The beams were similar to the Madison County Bridge beams, having an extended bottom flange which formed a keyway between them (see Fig. 7). A 2-in. (51 mm) concrete topping was placed over the assembly which was assumed to act compositely with both the slabs and the girders. The structure was completed in January 1952 and is still in service.

Deflected Strand

By the time the Kroger Store was completed (1951), we had received information on bond tests run on seven-wire strands indicating that strands up to 5⁄16 in. (4 mm) diameter could be bonded in 5000-psi (34.5 MPa) concrete. The block units for building slabs were redesigned to place the cables on the outside of the unit so it could be bonded for ultimate moment. We wrapped the cables around one end of the beam and anchored them at the opposite end with a spring-loaded aluminum fitting made by the Reliable Electric Company of Chicago.

The anchor was a modified telephone guy wire anchor. The barrel and cap were redesigned for greater loads. The strands were pulled through the anchors and extended about 15 in. (381 mm) to bond into the topping for final anchorage. The strand anchors were seated on cast split washers designed to accommodate the slope of the deflected strand (see Figs. 8 and 9).[4]

Early in 1953 we were assured that seven-wire strands, up to 3⁄8 in. (9.5 mm) diameter could be bonded in 5000-psi (34.5 MPa) concrete and our entire design and fabrication procedure for building products was revised. The fittings and the labor of tensioning were a significant part of the total cost of the product. We eliminated the fitting by placing the strands inside the cores of the units and grouting them.

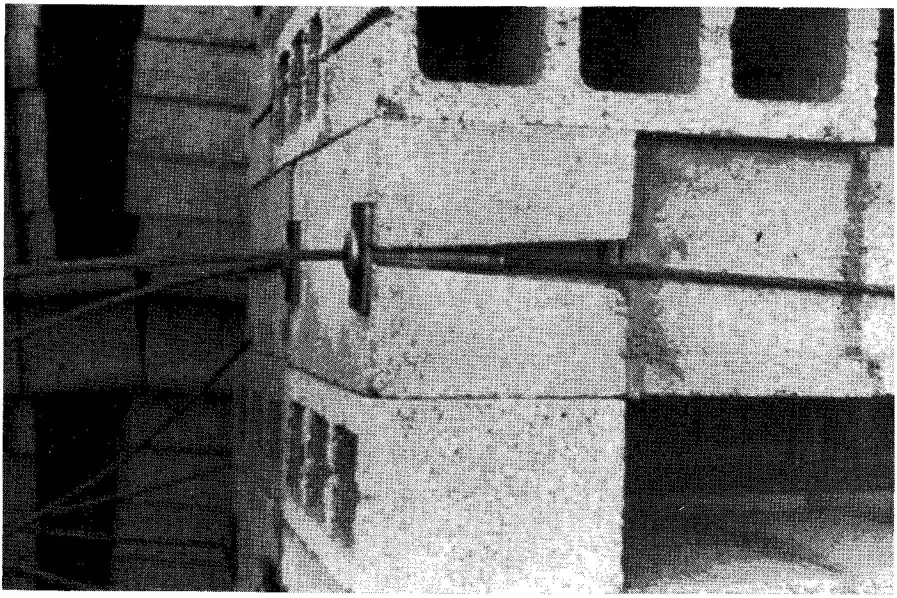
Fig. 8. An 8-in. (203 mm) building beam with bonded strands.

We reduced tensioning costs by making the beams in pairs, end to end, separated by a telescoping jacking frame with fixed anchor frames at each end of the beam line. The strands were run continuously through both beams and anchored at the end frames. A jack was then set in the telescoping frame and the beams jacked apart and the nuts set up on the frame. The strand

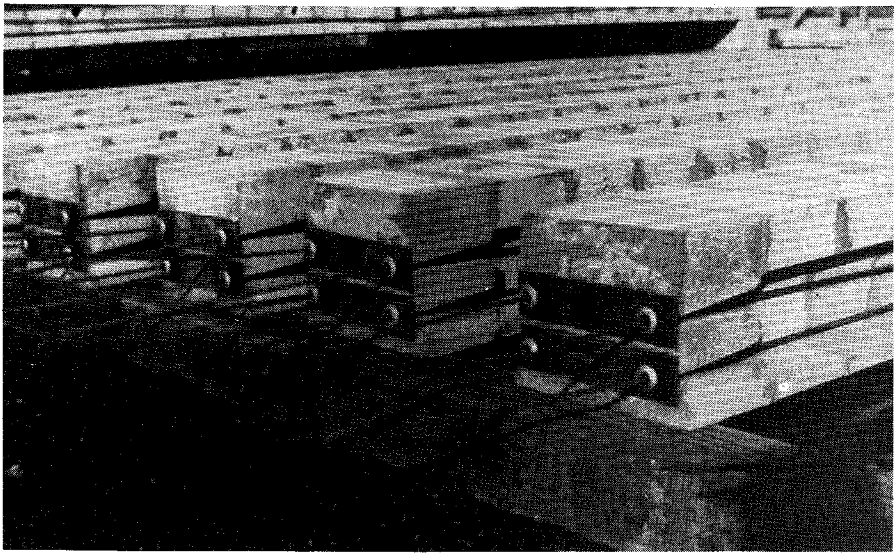
Fig. 9. A 16-in. (406 mm) bridge beam with bonded strands.

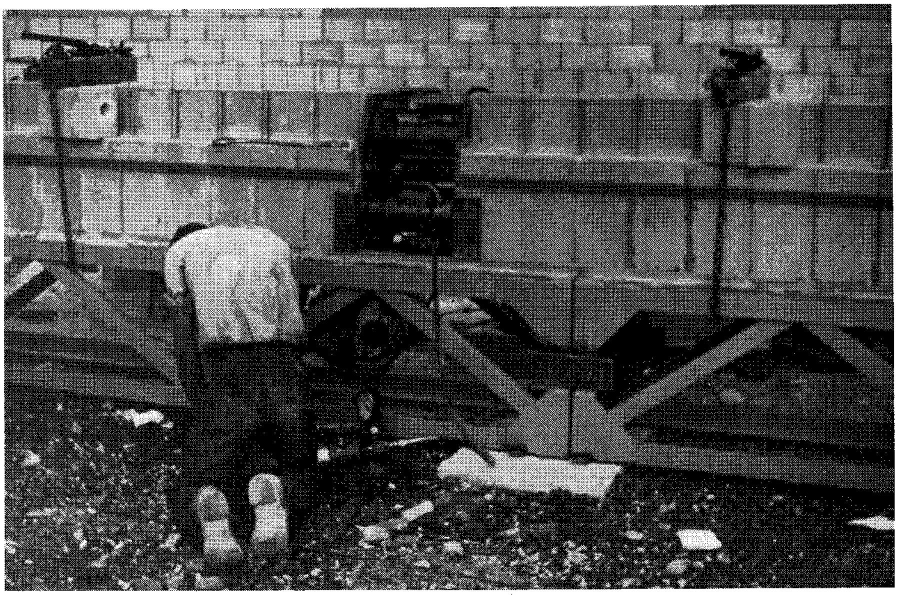

Fig. 10. Tensioning two 16x24-in. (406 x 610 mm) block building beams by jacking them apart.

cores were then grouted with 5000-psi (34.5 MPa) grout. When the grout reached release strength the strands were cut and the product removed from the bed (see Figs. 10 and 11).

This method of fabrication for building beams remained unchanged until about 1958 when block beams were replaced by precast pretensioned members. During this period several major structures were built. Among them were the 40,000 sq ft (3720 m^2) warehouse for General Shoe Corporation and the 100,000 sq ft (9290 m^2) manufacturing plant for the Crosley Corporation, in which the floors were designed for a floor load of 250 psf (0.02 MPa). The largest structure built of prestressed concrete block beams was the roof of the 800,000 sq ft (74,300 m^2) warehouse for the Wilkins Air Force Depot at Shelby, Ohio (see Figs. 12, 13, 14, and 15).

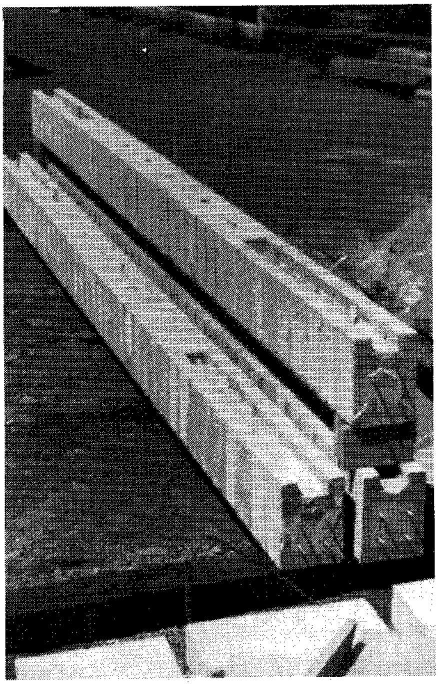

Fig. 11. 12 x 16-in. (305 x 406 mm) building beams with grouted strands. Note slot for continuity steel in 12 x 16-in. (305 x 406 mm) block.

Pretensioned Members

An economical roof system in use during the early fifties consisted of a 2-ft

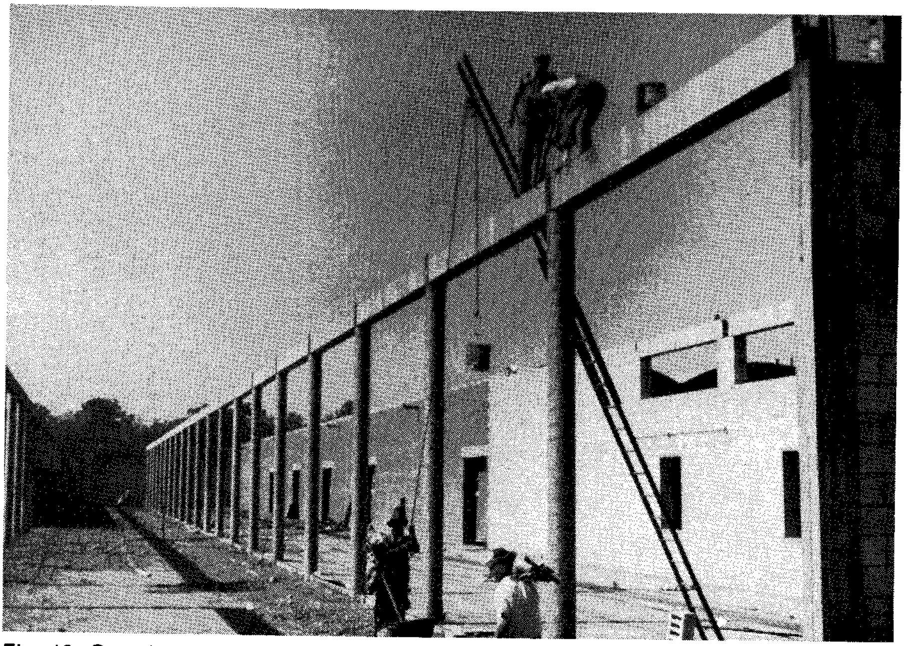

Fig. 12. Grouting continuity steel in 12 x 16-in. (305 x 406 mm) block beams of 40,000 sq ft (3720 m²) warehouse for General Shoe Corporation.

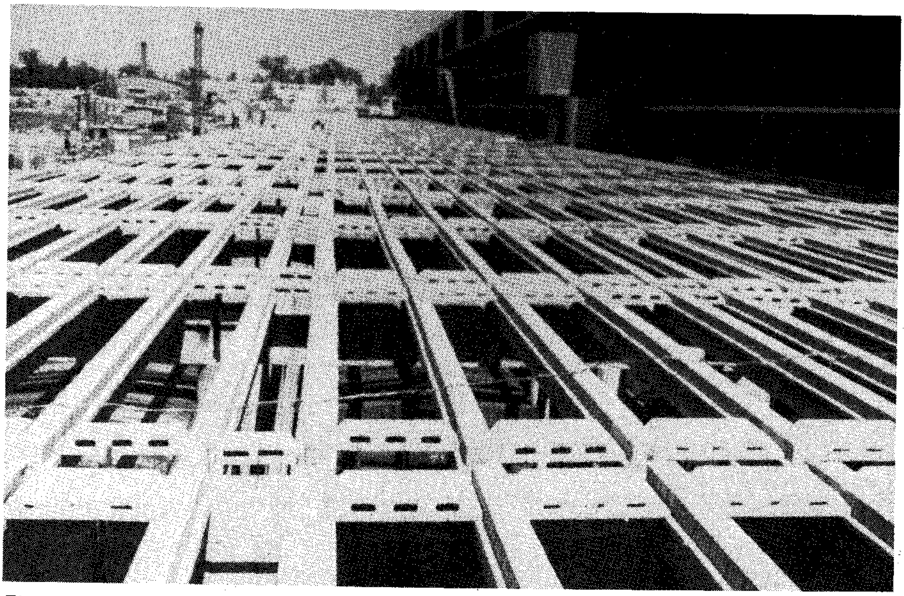

Fig. 13. Prestressed block joist and filler construction on 100,000 sq ft (9290 m²) warehouse for Crosley Corporation. Joists are made continuous over 18 x 24-in. (457 x 610 mm) prestressed block beams by reinforcing steel in the topping slab.

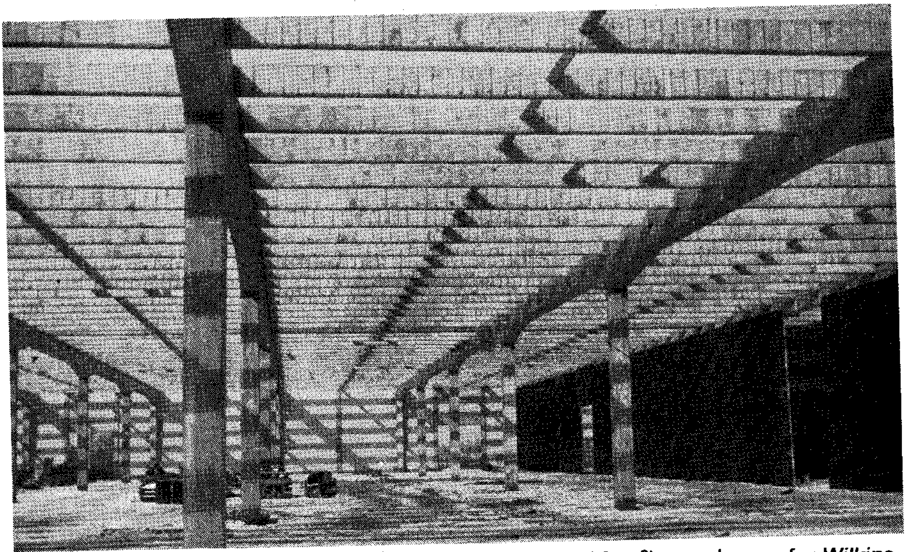

Fig. 14. Prestressed block joist on 800,000 sq ft (74,300 m²) warehouse for Wilkins Air Force Depot.

(0.6 m) wide precast concrete channel plank with 4-in. (102 mm) legs that would span up to 12 ft (3.7 m). It occurred to us that this member could be made more economical if it were made wider and the span increased by prestressing. This was the beginning of pretensioned slab construction in Tennessee.

The design of the new channel slab was based on using deflected strands because all of our prestressed block designs were based on this concept. In March of 1953 we constructed, at the

Fig. 15. Fabrication of joist for Wilkins Air Force Depot.

Fig. 16. Fabricating beds at a Breeko plant for producing pretensioned channel slabs with deflected strands. Built in March 1953.

Breeko plant, a pretensioning bed that was notable for two reasons. It was designed for deflecting strands, and it did not require anchorage abutments. The thrust of the strands was carried by the continuous block beams that supported the form (see Fig. 16).

The first production bed was 200 ft (61 m) long and could produce 3-ft (0.9 m). wide channel slabs, up to 14 in. (356 mm) deep, which would span 50 ft (15.3 m) for roof loading. As we all know, the channel slab soon gave way to the double-tee except for heavy floor loading.

In March of 1957 a portable steel bed for site casting was designed for Craftsman Construction Company of Denver, Colorado, to produce 8-ft (2.4 m) wide double-tees with deflected strands. The bed was self-stressing, i.e., it did not require anchorage abutments. The bed

Fig. 17. Continuity test at Breeko Plant. On the left is Lloyd Markham, at center Charley Scott. Man on right probably carried loading blocks. Taken in August 1952.

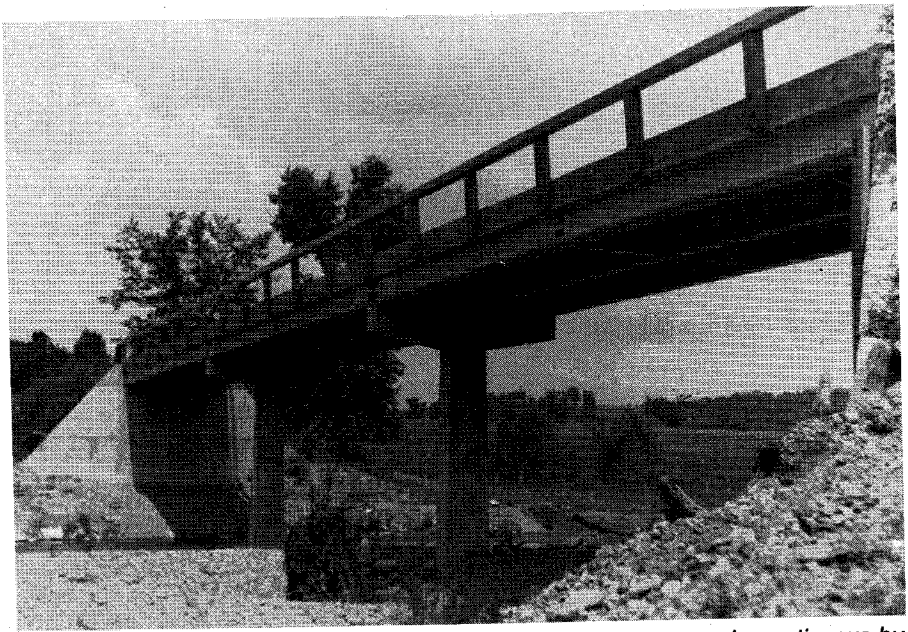

Fig. 18. Cheatham County Bridge of three 50-ft (15.3 m) spans made continuous by reinforcing in composite pour over supports. Pier caps are precast. Built in 1955.

was used to manufacture products for two large schools.

We began to establish continuity in prestressed products in 1952, by placing reinforcing steel in deep notches formed in the end blocks of block beams near supports. The first test beam was made in the summer of 1952 with three 20-ft (6.1 m) block beams, 8 x 9 in. (203 x 229 mm), prestressed with two 5/16-in. (8 mm) strands and made continuous over the two interior supports by placing two 5/8-in. (16 mm) reinforcing bars in a poured concrete keyway (see Fig. 17).

The interior supports were purposely offset so the cold joint between the beams was unsupported. We considered the test successful and proceeded to use continuity in all multispan structures using prestressed blocks, including bridge structures (see Fig. 18).

A more sophisticated continuity test was run by the Concrete Masonry Corporation of Elyria, Ohio, for the U.S. Corps of Engineers prior to fabricating the 33-ft (10.1 m) long, 8 x 18-in. (203 x 457 mm) prestressed block joist to be used on the 800,000 sq ft (74,300 m^2) warehouse at the Wilkins Air Force Depot. The test joists were continuous over three spans and were supported by concrete rigid frames (see Fig. 19).

A still more sophisticated continuity test was conducted by the PCA Laboratory at Skokie, Illinois, some 10 years later on prestressed bridge girders made continuous over supports by placing reinforcing steel in the composite slab.

In May of 1954 we designed a pretensioning bed for the T. L. Herbert and Sons Company in Nashville to take a prestressing force of 800 kips (3560 kN) and a strand deflection force of 30 kips (133 kN). The bed was elevated above ground, with slots for deflector rods at 5-ft (1.5 m) centers (see Fig. 20).

The first highway girders with deflected strands were produced on this bed in 1954 for the Ezell Pike Bridge in Davidson County, Tennessee. The

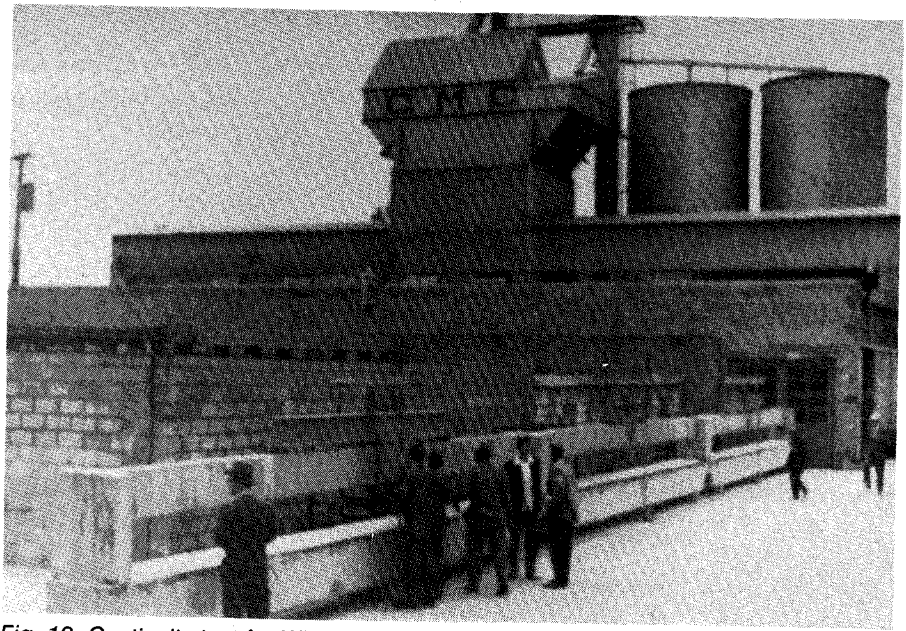

Fig. 19. Continuity test for Wilkins Depot joist.

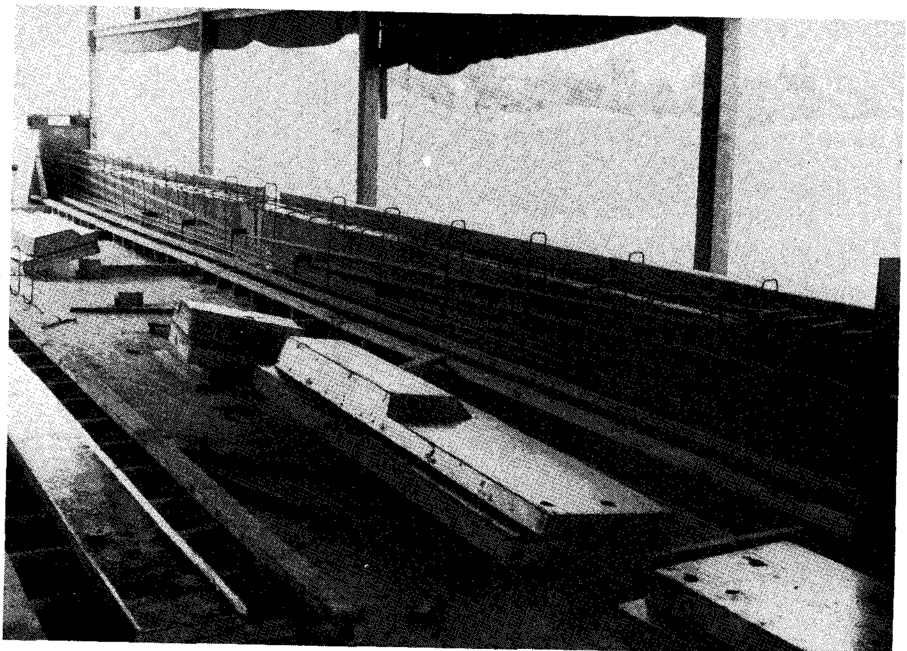

Fig. 20. T. L. Herbert bed for producing pretensioned girders with deflected strands. Built in May 1954.

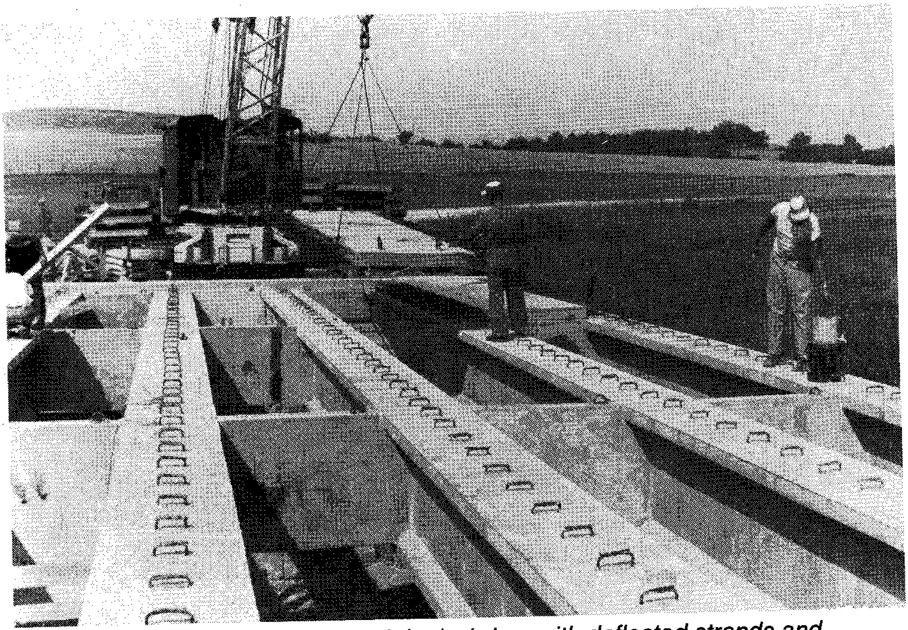

Fig. 21. Ezell Pike Bridge , 80-ft (24.4 m) girders with deflected strands and precast deck slabs. Built in 1954.

bridge has a span of 82 ft (25 m) and was designed for an H-20-44 loading (see Fig. 21).

The longest girders produced on this bed were the 102-ft (31.1 m) girders for the Milan Gymnasium, Milan, Tennessee (see Fig. 22). The bed was in service for about 4 years when it was replaced by a bed on grade with deflector rails.

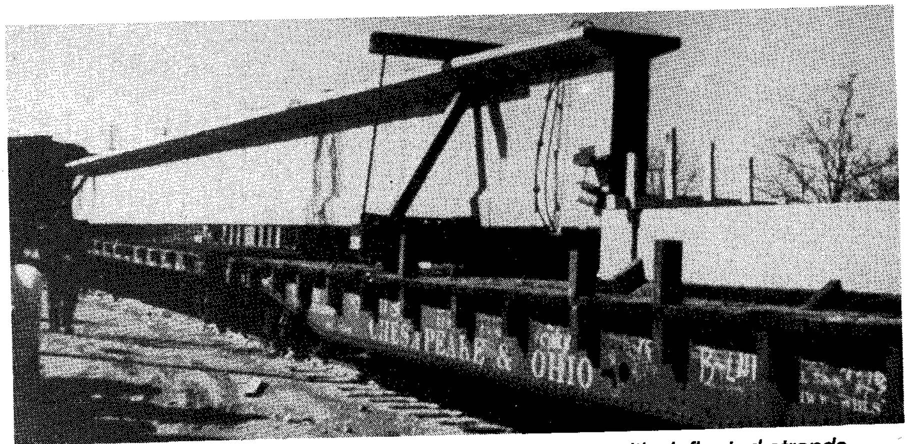

Fig. 22. Milan Gymnasium girders, 102 ft (31.1 m) long, with deflected strands. Built in 1955.

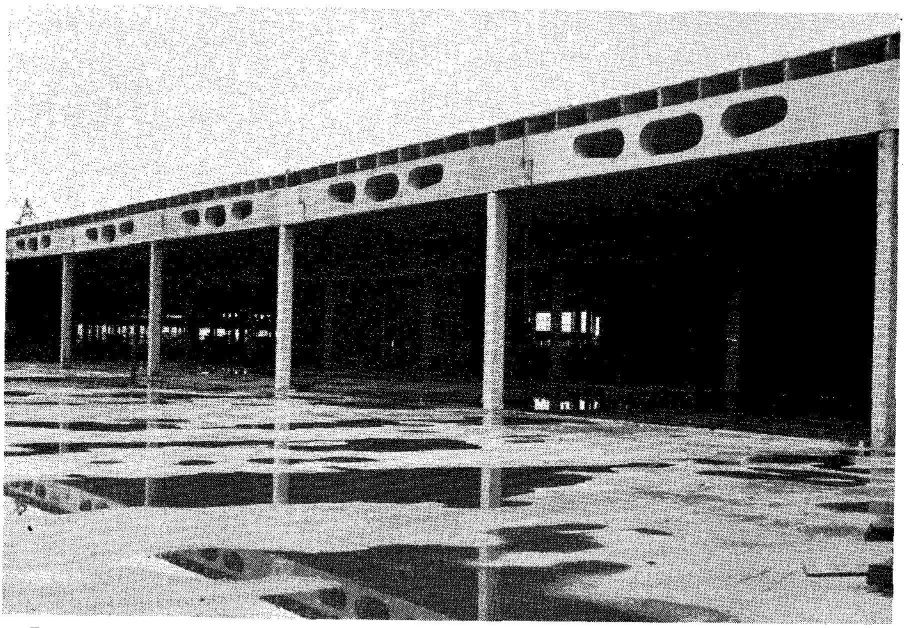

Fig. 23. Open web joist on 40-ft (12.2 m) spans, made continuous by post-tensioning. Built 1964 for Celanese Corporation. Designed by Ross H. Bryan; fabricated by Concrete Materials, Charlotte, NC (Pete Verna).

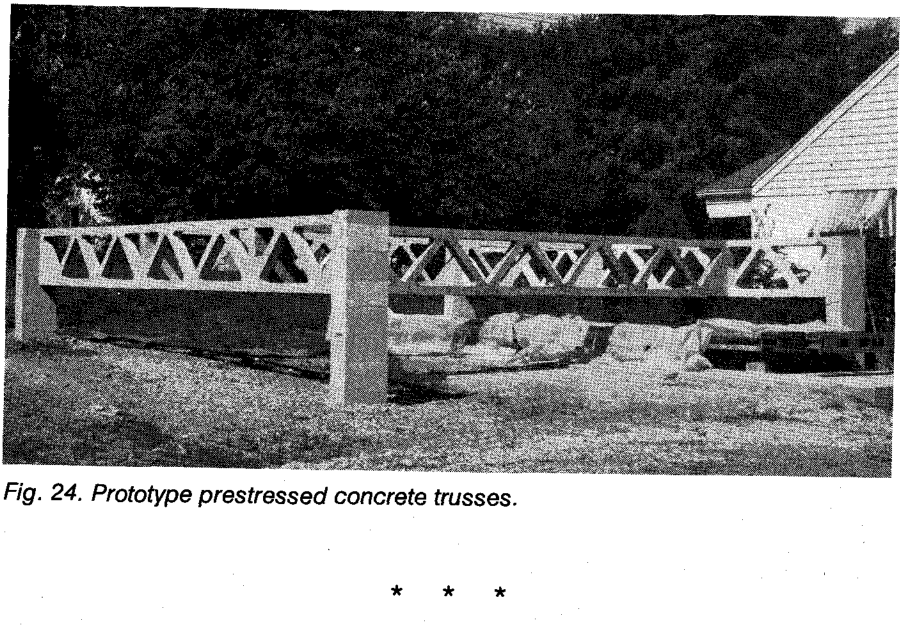

Fig. 24. Prototype prestressed concrete trusses.

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Closing Thoughts

We continued to improve on the design of the pretensioning beds in the ensuing years. Heavy steel jacking beams were replaced by armored concrete buttresses. The end anchorages were designed to resist overturning, using the moment resistance of the deflector beams combined with a variable soil resistance curve. Deflector rails continued to be a problem and still are today.

One major reason for the success of the prestressed concrete industry is that during those early years we anticipated each fresh challenge. The answer came in the form of new products, more efficient cross sections, more economical production techniques, and more imaginative design and construction methods.

No industry can survive without looking towards the future. We must be constantly on the alert and looking towards ways to do things better in the face of new demands and future markets.

Described below is one concept that might merit consideration. If this idea is more fully developed it would add considerable flexibility to prestressed concrete construction. My suggestion is to produce an open web truss/joist system (see Fig. 23). Recently, we designed and tested such a truss (see Figs. 24, 25)[6] and established a design procedure. Unfortunately, we have not, as yet, been able to come up with an economical fabrication procedure.

If such a joist/truss system could be made on a production line basis and an insulating structural slab made to span about 12 ft (3.7 m), or even 8 ft (2.4 m), prestressed concrete could capture a vast market that is presently closed to the industry.

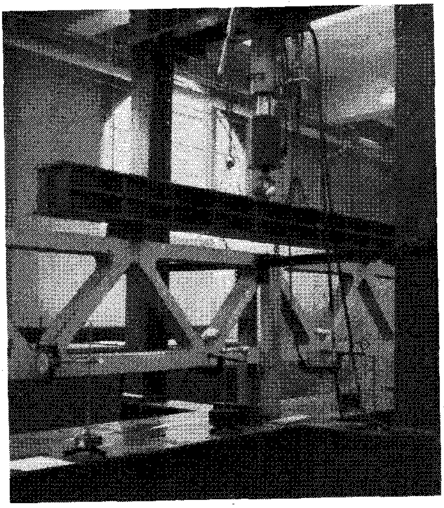

Fig. 25, Prototype truss undergoing testing in laboratory.

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