became acquainted with concrete construction as a child because my father was a contractor. His desire was that my brother Thomas and I follow his footsteps and carve out a career in construction. In fact, my father's ultimate goal was to have his two sons become "Anderson Brothers, General Contractors."

Our training started at an early age, in Tacoma, Washington, shortly after World War I. It was a time when low-slump concrete was hand-mixed and compacted by "rodding" with long slender wooden sticks. When not in school, my brother and I were kept busy much of the time on construction sites.

Our first mixer, a one-wheel-barrow capacity, single-cylinder gas engine-powered device purchased in the early twenties, was a major advance from hand-mixing, and greatly increased our productivity. A batch consisted of 1 scoop of cement, 3 of sand and 5 of gravel, mixed with about a gallon of water. No slump or cylinders test were required, and the compressive strength of the concrete was probably around 2000 psi (13.8 MPa). Foundation walls and footings 6 in. (152 mm) thick, were plain concrete—no longer permitted by today's codes.

In 1927, we moved up to a steam-powered mixer of 1 cu yd (0.76 m³) capacity. Its boiler was fueled with scrap lumber. As a mixer operator, I also had to stoke the
boiler—not a comfortable job on hot summer days.

By the time I graduated from high school in 1928, I was a qualified concrete worker. Projects grew in size, and ready-mixed concrete appeared on the scene.

Suddenly, the crash came in 1929, causing an abrupt halt in construction. To better my prospects, I enrolled in the College of Engineering at the University of Washington in Seattle, majoring in civil-structural engineering. In retrospect, my career in engineering can be credited to the "Great Depression."

After obtaining my bachelor's degree, I was fortunate enough to do graduate work at Massachusetts Institute of Technology in Cambridge; and to be inspired by Professor Roy W. Carlson, one of the world's top experts in concrete. My first research project, entitled "A Study in Subaqueous Concrete," was carried out under Dr. Carlson's tutelage, and published in the January 1937 ACI Journal.

After obtaining my doctorate from MIT, I spent a year (1938-39) in Germany working for Bauer & Scharte & Max Klone as a design engineer. Although I was involved mainly in designing welded steel bridges, the training and experience I received were useful later in my career.

As the dark clouds of World War II gathered, I was fortunate to return to MIT. For the next 2 years (1939-41) I worked on the development of bonded wire electric strain gages as a research associate in collaboration with Professors A. V. DeForest and A. C. Ruge. At the time, I little realized that the laboratory experiences I gained in instrumentation, testing and stress analysis of concrete would prove to be invaluable 10 years later in field testing the prototype Walnut Lane Bridge girder.

From 1941 to 1945 I became involved in the construction of welded steel naval vessels—quite a departure from concrete but useful background when 30 years later ABAM
and Concrete Technology designed and built the giant ARCO pre-stressed LPG vessel.

In 1946, I opened my own consulting office in Springdale, Connecticut. At the time, wire resistance strain gages (such as the Baldwin SR-4 type) were being used increasingly to determine strains, and thereby the stress distribution, in machines and structures.

I had long felt there was a need for a rapid, simple, yet reliable means to find the stress intensity at several locations in a loaded structural member. Subsequently, I developed a strainmeter (Anderson Model 301 Strainmeter) which could accurately and rapidly measure static strains at a number of gage locations. This instrument could accommodate 24 strain gages, thus eliminating the necessity for disconnecting and reconnecting gage wires for each gage reading.

Later, I also developed a bridge balancer (Anderson 302 Bridge Balancer) which, while combining the features of the earlier strainmeter, could measure strains under combinations of static and dynamic loads.

The availability of these instruments plus the testing techniques I developed in the field proved very useful when it came time to test the Walnut Lane Bridge prototype girder.

Walnut Lane Bridge

My introduction to the Walnut Lane Bridge was through my good friend, A. G. Formel (Construction Manager of the Preload Corporation). He called me one day in 1949 to tell me about the project and the City of Philadelphia’s plans to
test to destruction a 160-ft (49 m) prototype girder of the bridge. Being aware of my training and experiences in field testing and instrumentation, Formel encouraged me to apply for the testing job—which I did.

I was interviewed by Thomas Buckley, Director, Department of Public Works of the City of Philadelphia, and other key members of his staff. Today, I still vividly remember the interview which was as intense and thorough as the oral examination for the Doctoral degree at MIT.

The person responsible for testing the prototype girder was required to be at the job site continuously during the entire fabrication and stressing operations. He had to be there at all times to record the strains and measure the deflections of the girder as it was incrementally loaded.

My instrumentation plan and testing procedure were submitted to the City of Philadelphia, Department of Engineering and Surveying. The proposal was reviewed by Samuel Baxter, Assistant Chief Engineer, and his staff, then forwarded to Professor Gustave Magnel (Fig. 1), the designer of the Walnut Lane Bridge and the world's foremost expert on prestressed concrete testing, design and construction, at the University of Ghent in Belgium, for his approval.

The City of Philadelphia was careful to point out that Professor Magnel's seal of approval was imperative if fabrication and testing of the girder were to proceed. To our delight, Professor Magnel liked my instrumentation plan and testing procedure.

Details of the design, testing and construction of the Walnut Lane Bridge have been well publicized in References 3 through 10. In addition, Zollman recently gave an excellent overview of the events surrounding the Walnut Lane Bridge. Therefore, in this article I will only summarize the highlights involved in instrumenting and testing the experimental girder.

The test girder, nearly 160 ft (49 m)
Fig. 3. Elevation of Walnut Lane test girder showing location of electric strain gages.
long, 4 ft 4 in. (1.3 m) wide at the top and 6 ft 7 in. (2 m) deep, was a modified I-beam, weighing about 160 tons (145 t). The girder was cast at the job site using ready-mixed concrete containing 800 lbs of cement per cu yd (1424 kg/m³). Much of the success for the fabrication of the concrete test girder was due to Clement Atchit (Fig. 2), resident engineer from Blaton Aubert, Brussels, Belgium.

Prior to post-tensioning, 22 SR-4 strain gages were applied to the surface of the concrete. Fig. 3 shows the location of these gages.

I was responsible for the instrumentation (Fig. 4), strain readings and deflection measurements.

The gage locations were rubbed to a smooth plane surface, wire brushed, and a film of 0.010-in. (0.25 mm) thick celluloid was applied to the prepared surface with a generous coating of household Duco cement.

This coating was allowed to dry for 2 days and then the film was sandpapered smooth. The SR-4 gages were then applied to the celluloid film with Duco cement and allowed to dry for 2 days. Fig. 5 shows the gage as applied over the celluloid film to the concrete.

After the gages were thoroughly dried, a coat of waterproof Petrosene wax was applied and the concrete around the gage area was coated with lacquer to provide a moisture barrier. Wiring from the strain gages was run to a small instrument shelter in which two Anderson Model 301 strainmeters were located (see Fig. 6).

Sixteen days after the concrete was cast, post-tensioning of the girder by the Blaton-Magnel system commenced, and this operation was completed in 5 days. The prestressing caused the center of the girder to deflect 1¼ in. (32 mm) upward from the temporary cribbing.

Strain readings obtained during the prestressing operation were recorded. Young’s modulus of elasticity of the concrete, $E_c$, was established from stress-strain data taken on test cylinders at 17 and 21 days.

Using a value of $E_c = 3,500,000$ psi (24,130 MPa) for the concrete at the time of prestressing, the stress at the girder center from strain data was compared to calculated values for the post-tensioned condition:

<table>
<thead>
<tr>
<th>Girder location</th>
<th>Strain data</th>
<th>Computed values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top fibers (comp.)</td>
<td>1050 psi (7.24 MPa)</td>
<td>1120 psi (7.72 MPa)</td>
</tr>
<tr>
<td>Bottom fibers (comp.)</td>
<td>1990 psi (13.72 MPa)</td>
<td>1885 psi (13.00 MPa)</td>
</tr>
</tbody>
</table>

Load tests were made using eight hydraulic jacks spaced at 20-ft 8-in. (6.3 m) intervals along the girder. Steel frames ballasted to the ground by ingots pro...
Fig. 6. Two Model 301 strainmeters used with the electric strain gages. Compensator gage is located on the test cylinder below.

vided the reaction for the jacks shown in Figs. 7 and 8.

To obtain accurate load increments, steel bars with SR-4 gages attached were located over each jack (Fig. 9) as the hydraulic pressure gages in the jacks were known to be inadequate for the small load increments up to the working load. Because of the large deflections in the girder at the higher loads, stability of the load frames became critical, and the strain gage bars had to be removed from the jacks after the cracking load of 1400 lbs/ft (2100 kg/m) was reached.

Fig. 9 is not mentioned in the text.
The so-called cracking load for this test girder requires a word of explanation. A settlement crack had formed in the girder before prestressing, which closed completely after the stressing of the wires. A strain gage was applied across the crack and at the above-mentioned load it indicated a sudden abnormal increase, showing that the crack was reopening.

Thus, at the 1400 lb/ft (2100 kg/m) loading of the girder, the compression of the bottom fibers at midspan was exhausted and further loading transformed the section from a prestressed to a conventional reinforced concrete girder.
failure occurred at 3:00 p.m., October 27, 1949.

Failure was in the top flange to right of the stiffener. (Had no crack existed in the girder before prestressing, the cracking load would have been the load at which the concrete ruptured in tension.)

The moment of inertia of the midspan section at this juncture dropped from 1,250,000 to 272,000 in.\(^4\) (0.052 to 0.113 m\(^4\)). Load indications at the higher values were obtained from the Bourdon-type pressure gages on the jacks, and they were not sufficiently reliable for analysis purposes.

Fig. 10 shows a general view of the test girder when loaded to the capacity of the jacks. The midspan deflection was 15 in. (381 mm). The final loading to destruction was carried out by placing an additional 59 tons (53.5 t) of ingots on the girder at midspan. Figs. 11 and 12 show a general view and closeup of the failure.

To correctly evaluate the load test strain readings (and hence the stress distribution in the concrete girder), an accurate determination had to be made...
of the modulus of elasticity of the concrete. It soon became apparent that the value of the modulus of elasticity fluctuated greatly depending on the age of the concrete and the method used to determine its value.

To gain some reliability, three independent methods were used to determine the modulus of elasticity of the concrete:

(a) Compression tests on two 38-day job-cured cylinders were made with a pair of SR-4 strain gages located on opposite sides of each cylinder to give average stress-strain curves (see Fig. 13). From the cylinder stress-strain data given in Fig. 13, the value for $E_c$ was found to be 4,600,000 psi (31,720 MPa).

(b) The fundamental frequency of the girder was measured when excited into vibration by men jumping on it. Fig. 14 (top) shows oscillograms obtained with a brush recorder connected to strain readings on the girder for the vibration test. The average frequency recorded was 2.16 cycles per sec. Using a simple calculation method (see Fig. 14), $E_c$ was found to be 6,550,000 psi (45,160 MPa).

(c) Calculations were also made from the slope and deflection measurements obtained from the load tests. From these computations $E_c$ was found to be 6,000,000 psi (41,370 MPa).

Values for the modulus of elasticity
Fig. 14. Two sample oscillograms and calculation method for evaluating modulus of elasticity of concrete (Walnut Lane test girder).

determined by stress-strain data were considered too low whereas a value averaging those obtained by the frequency and slope and deflection measurements [(Methods (b) and (c))] was considered more representative.

In general, the data obtained from the Walnut Lane girder tests were considered valuable in verifying the design of the bridge. Strain, slope, and deflection measurements obtained were in good agreement with theoretical values.

The experience gained from the test indicated the importance of good load indicating methods, and a need for obtaining accurate stress-strain curves up to ultimate loads. It also pointed up the difficulties in obtaining a representative value for the modulus of elasticity of the concrete and in estimating creep and shrinkage in the concrete and relaxation in the prestressing steel.

The performance of the prototype girder under all loading stages, up to and including ultimate, exceeded all expectations. Although Professor Magnel correctly predicted the behavior of the girder he confided to us that had he known Americans were capable of producing such good concrete and prestressing steel he would not have been quite so conservative in the design of the girder! (It must be appreciated, of course, the Belgian professor was skeptical regarding American quality control and production methods.)

The entire concept that a major structure could be designed and built using prestressed concrete stirred the imagination of the bridge building fraternity in the United States. The test to destruction of an experimental girder was the proof of the pudding that such a concept could be attained realistically.

The successful instrumentation and testing of a full-sized prestressed girder is historically significant because it instilled public confidence in prestressed concrete and marked the beginning of sophisticated instrumentation and testing procedures for the product.
Pottstown Test Girder

In the spring of 1950 (a few months after the Walnut Lane experimental girder was tested), I was called upon to load test to destruction a full-scale 30-ft (9.15 m) prestressed bridge girder for Concrete Products Corporation of America in Pottstown, Pennsylvania. The Pottstown test was significant in two ways: (1) the girder was cast and pretensioned at the plant and (2) for the first time seven-wire strand was used to prestress the girder.

Fig. 15 shows a plan, side view and enlarged sections of the girder together with the location of the strain gages. The 30-ft (9.15 m) test girder was manufactured using the Hoyer method.

Fig. 15. Plan, side view and sections of Pottstown test girder showing location of strain gages.
of pretensioning the wires before casting the concrete. Fig. 16 shows the details of the reinforcement and Fig. 17 is a closeup of the jack and anchorage of the pretensioned wire.

In order to measure the compression prestress in the bottom fibers of the girder from the tension force of the wires, it was necessary to embed special strain gage units in the concrete. These units were made by attaching SR-4 gages to curved metallic members (see Fig. 18).

After calibration, the units were embedded in blocks of concrete mortar, which provided protection against moisture and rough treatment when placing concrete around them. The circuit used with these gages provided temperature compensation within the unit—a considerable advantage for field test projects subjected to extremes in weather.

Fig. 19 shows the gage units in the form, ready to be embedded in concrete. In Fig. 20 the girder is about half cast, showing the paper tubes used to form voids in the concrete.

After obtaining the strain readings due to release of the ends of the pretensioned wires, the girder was set up for

Fig. 18. Special strain gage units, each containing four SR-4 gages encased in small blocks of concrete mortar after calibration.
Fig. 19. Form ready for concrete, showing internal strain gages on bottom of beam.

Fig. 20. Girder is about half cast, showing paper tubes used to form lightening holes through beam.

Fig. 21. Strainmeter setup for measuring strains during prestressing operation.
Fig. 22. After destruction test, 74,990 lbs (334,000 N) of ingots were placed on center of beam. Note that strainmeter is in foreground. (Pottstown prototype girder.)

Fig. 23. Closeup of fracture. Note wires leading to strain gages on beam. (Pottstown prototype girder.)
load tests. Additional SR-4 gages were installed at several locations on the concrete surface, using a similar procedure as was done for the Walnut Lane strain gages. Fig. 21 shows the strainmeter setup for measuring strains during the pretensioning operation.

The load tests were accomplished by loading steel ingots directly on the girder. Since each ingot had been accurately weighed beforehand, the weight being marked on the ingot, it was simple to record the loads. Figs. 22 and 23 show the girder and test setup after loading to destruction.

As had been done for the Walnut Lane tests, the modulus of elasticity of the concrete was obtained by three different methods:

(a) Test cylinders with SR-4 gages attached to opposite sides of each cylinder to give average strain during compression loading. From these results the modulus of elasticity of the concrete $E_c$ was determined to be 3,180,000 psi (21,930 MPa).

(b) Frequency measurement of the girder vibrating in its fundamental mode. The value for $E_c$ was found to be 3,080,000 psi (21,240 MPa).

(c) Deflection of the beam. The value for $E_c$ obtained was 3,240,000 psi (22,340 MPa).

Measured and calculated strains for the top and bottom fibers of the test girder are plotted in Fig. 24.

Further Developments in Instrumentation

The Walnut Lane and Pottstown prototype girder tests were significant milestones not only in the public acceptance of prestressed concrete but also in paving the way for improved instrumentation techniques both in the field and laboratory.

As mentioned earlier, a better method needed to be found to determine the creep and shrinkage of concrete, and steel relaxation (and hence the prestress losses) in a prestressed member over a period of time. One major problem was
to find a reliable means to measure the loss of tension in prestressing steel with time. Most prestressing systems did not allow ready access to the wires inside the concrete. In particular, the Freyssinet system of encasing the tendon in a metal sheath before concreting was an example of the inaccessibility of the wire for strain measurements.

An ingenious scheme was devised by Frank Hines to overcome this drawback (see Fig. 25). The prestressing wires are separated for a short distance by two discs rigidly supported by a piece of pipe. The pipe also provides a passage for the grout through the cable without disturbing the strain gages.

A somewhat simpler scheme for measuring wire tension utilizes the measurement of lateral deflection of the wire for a given transverse load. A simple device (see Fig. 26), consists of a stiff bar with clamps at the ends attached to the wire.

At the center of the bar, a micrometer head is arranged to deflect the wire transversely. The load required for a given deflection is indicated by strain gages attached to the bar to indicate the bending moment at the center of the bar.

The load-deflection relationship for the wire is given in Fig. 26.

Application of this device was found to be particularly useful in determining the loss in steel tension in a pretensioned beam due to creep, shrinkage and steel relaxation (see Figs. 27 and 28).

* * *

Meanwhile, my brother Thomas, after acquiring degrees from the University of Washington and Massachusetts Institute of Technology, had pursued a career in civil engineering and general construction. He was engaged in various general contracting in Washington State from 1938 to 1941, then served in the United States Navy, with the Sea Bees, during World War II.

At the time of the Walnut Lane Bridge project, in 1948, Tom had resumed his contracting business in Tacoma, Washington. However, my father, Eivind Anderson still hoped to unite his sons in a family construction firm. The growing interest in the new (to America) techniques of prestressing concrete, in the wake of the Walnut Lane Bridge and other early projects, made prestressed concrete construction a logical choice for this proposed family enterprise. We had all accumulated much experience with concrete, and I had already become involved with the developing prestressing industry in America.
The load-deflection relationship for the wire is:

\[
y = \frac{Pj}{2T} \left[ \frac{1}{2} U - \tanh \frac{1}{2} U - \frac{(1 - \cosh \frac{1}{2} U)^2}{\sinh \frac{1}{2} U \cosh \frac{1}{2} U} \right]
\]

where

- \( y \) = deflection
- \( P \) = transverse load producing the deflection
- \( j = \sqrt{\frac{EI}{T}} \)
- \( E \) = Young's Modulus of wire
- \( I \) = moment of inertia of wire section
- \( T \) = tension in wire
- \( L \) = length of the wire
- \( U = \frac{L}{j} \) radians

Fig. 26. Transverse load-deflection device for measuring tension in a prestressing wire.

Fig. 27. Application of wire tensometer to determine bond transmission and prestress losses.
European Tour

Before setting up the new venture, all three Andersons agreed it would be prudent to visit the European centers of prestressed concrete development. This would give us a better idea of what had already been done with prestressed concrete in Europe and what new developments and research were in progress. This background information would be essential if we were to assess accurately the potential of prestressed concrete in the United States, and to make our projected company a success.

The 2½-week trip, in early October 1950, covered France, Switzerland, Belgium, Sweden, and England. There we visited precast prestressing plants, construction sites, and research laboratories and had the opportunity to meet and converse with the leading experts in prestressed concrete engineering, design and construction.
In France, the leading company in prestressed concrete engineering was the Société Technique pour l'Utilisation de la Précontrainte (STUP), the engineering firm created by the French prestressing pioneer, Eugene Freyssinet. STUP held the patents for the Freyssinet prestressing system, then used extensively in France and other parts of the world.

France had many, and varied, examples of prestressed concrete construction, including bridges, hangars, aircraft landing fields, dams, tunnels, piers, revetments, railroad ties, water conduits, caissons, and silos. The Director of STUP, M. Burgeat, kindly arranged for us to visit two of their current projects. Both of these used precast prestressed units, post-tensioned together.

The first of the two STUP projects we visited was a 5850-ft (1783 m) covered viaduct under construction in Rouen (Fig. 29). The precast prestressed units were post-tensioned together, forming spans varying from 26 to 58 ft (7.9 to 17.7 m) in length. When complete, the viaduct would carry two railroad tracks within the box and a super-highway on the upper deck (Fig. 30).

The structure in Orleans was a water reservoir built to include operating and office space in the lower levels, and water storage above. Achieving this design would have been very difficult, and probably impractical, without using prestressed concrete (Fig. 31).

In Switzerland we were impressed by the prefabricated prestressed flooring known as "Stahlton planks" produced by Stahlton A.G., headquartered in Zurich. We visited their plant at Frick, where the clay tile sections that composed the plank were made, and stressed together. These prefabricated floor components made possible savings of weight, materials, and cost when erecting building floor systems.

We also saw some projects using the BBRV button-headed wire post-tensioning anchorage system.

In Belgium, we visited Professor Magnel's laboratory at the University of Ghent, and the engineering firm Bla-
Professor Magnel and M. Blaton-Aubert. Professor Magnel and M. Blaton had been the prime consultants for the Walnut Lane Bridge and we were eager to see what else they had done.

Professor Magnel was at this time acknowledged as the world's foremost authority (together with Freyssinet) on prestressed concrete. His laboratory was magnificent and the most advanced research center in the world. Indeed, engineers from all over Europe and, increasingly, America, were coming to learn from him (Fig. 32). Professor Magnel was very helpful and generous in sharing his knowledge with us.

Blaton-Aubert was working on several projects which used the Magnel "sandwich plate" post-tensioning anchorage system. We were able to visit some of these, including a warehouse under construction in Ghent (Fig. 33 and 34).

This project, similar to others we saw, used precast segments which were cast on site. Thus far, we had been impressed by the economy of the material, but concerned by the necessary on-site labor, which would cost much more in the United States. This labor cost could keep cast-in-place prestressed concrete from being fully competitive with other building materials.

Our visit to the A. B. Betongindustrie prestressed concrete (Strängbetong) plant in Stockholm, Sweden, was...
perhaps the high point of the entire trip. Using factory mass production techniques, they produced a large variety of consistently high quality precast prestressed standard building elements, including rectangular and I-section straight and saddle beams, piles, and planks (Fig. 35).

Here, then, was the answer to the discouraging amount of site labor necessary at most of the projects we had seen previously—precasting standard segments at a factory rather than individually, on-site. The Swedes were constrained by climate, with the impossibility of casting outdoors so much of the year, as well as by the highest labor costs in Europe; we in America by the high cost of labor. The same technique could enable prestressed concrete to be a competitive construction technique for both countries.

In England, we visited a similar precasting plant where prestressed products were being manufactured but on a somewhat limited scale. Nevertheless, the potential and economy of plant-fabricated elements became apparent.
Based on our experiences in Europe (particularly in Sweden and England), we were convinced that prestressed concrete would have to be mass produced under controlled factory conditions to be successful in America. The stage was thus set for me to rejoin my father and brother back in Tacoma where we would plan our joint venture in precast prestressed concrete.

In the next issue of the JOURNAL I will recount how we established our plant and began our life-long career in prestressed concrete.

References

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Chapter 2. Considerations for Segment Design. Presents recommendations for segment dimensions and details of segment design.

Chapter 3. Analysis of Precast Segmental Box Girder Bridges. Emphasizes aspects of design that differ or require more detailed consideration than more conventional types of prestressed concrete structures. Includes procedures for design for creep, shrinkage and temperature differential as well as analysis and correction of deformations required to control structure geometry.

Chapter 4. Fabrication Transportation and Erection of Precast Segments. Provides recommendations relative to construction aspects and their consideration during the design phase.

Chapter 5. Design Example, North Vernon Bridge, Indiana. A detailed illustration of design procedures and calculations for a three-span precast segmental bridge.

Appendix. Includes tentative design and construction specifications for precast segmental box girder bridges, summary of precast segmental box girder bridge sections in the United States and Canada, complete notation, and references.

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