LONG SPAN, PRESTRESSED CONCRETE BRIDGE CONSTRUCTION

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The year 1969 was the 20th anniversary of the first prestressed concrete bridge in the United States, the Walnut Lane Bridge in Philadelphia, and it's still going strong. This bridge was quite an engineering accomplishment, and we can be very proud of it.

But the idea of prestressing is not new. It is almost as old as reinforced design methods. The Egyptians, during the fifth dynasty, tightened ship hulls with ropes and turnbuckles to protect the hulls against penetrating water in heavy seas. They knew that by prestressing the overlapping boards the joints were tightened and the water entrance was cut to a minimum. Later, during the Renaissance, the building masters applied heated metal chains to construct long-span shells and cupolas.

When man started to investigate the application of prestressed concrete, he was lacking two fundamental items: high-strength concrete and high-strength steel. As soon as man invented the vibrator to consolidate concrete, it increased the density and helped ease the problem. As a matter of fact, P. H. Jackson, in 1886, filed the first patent on prestressing in the United States (#375999). His invention was a bar system with threaded ends and a nut which was turned. As the nut was tightened, the tensioning force was applied.

Until the end of the first World War, only lab trials in prestressed concrete were made. From 1919 to 1936 we had the first industrial applications of prestressed concrete for beams, slabs and silos. Very small spans with beams and slabs were accomplished, but nothing exciting. But in 1936, Dr. Fr. Dischinger in Europe, designed and built a prestressed concrete bridge spanning 225 ft., using post-tensioning cables. Quite an accomplishment!

During the second World War, engineers were looking for savings in material, a search which is still going on. This search for economy accelerated the research on prestressed concrete. Since 1952 prestressed concrete has won a permanent place in our growing economy.

Prestressing is here, and it's going to expand. When one thinks of the industrial expansion since the '50s, one doesn't realize how many trucks move over our highways and bridges. When these heavy trucks move across bridges, engineers know how much energy has to be absorbed. The concrete arch or frame bridges we were building 30 to 50 years ago were very exciting. We could span 50, 100, 150, 200, even 300 feet. But we know that an arch is only economical if the abutments don't yield. If the abutments yield we have to put more money in the foundations. If the live load is increased on an arch bridge, it will induce undesirable vibrations; therefore, the designer has to consider the ratio of live load to dead load. From these arch bridges engineers started to adapt their designs to faster moving car traffic. Instead of curved lines for the superstructure, the bridge lines became parallel, slender lines combined with slender piers to form a rigid frame system.

Modern prestressed concrete bridges give an impression of slenderness and open space. The driver doesn't feel as if he's going through a tunnel. For long-span concrete bridges, prestressing turned out to be the answer in design and construction. Engineers should design for continuity, because it has tremendous advantages. We know when a bridge pier settles, additional moments are induced over the supports. In prestressed concrete, these additional moments will not require the use of additional steel. Because of the prestressing, we are inducing elastic shortening and creep. This creep will help us and, instead of getting additional negative moments, we're reducing these negative moments appreciably. Also, if we combine slender prestressed concrete beams with slender columns, we have achieved an elastic system which will absorb longitudinal movements. Also, the resilience from non-elastic deformation is larger with prestressed concrete than with steel beams.

The next question is: How much does it cost to build a concrete bridge, and what are the factors that will determine these costs? Three major items determine the cost of a bridge structure: (1) material, (2) labor, and (3) forms. Today's design engineers have developed, with the help of computers, minimum dimensions for any chosen system. If we cut the sections further, the quality is lowered. With the help of computers, we have developed an advanced engineering society. Some of these delicate cross-sections need more labor than the ones we used 20 years ago. In prestressed concrete we are working with active forces which have to be placed properly to make prestressing work against gravity loads. Now, this last item has been put under a magnifying glass by many good engineers and contractors alike. Let's look at some of the methods of construction for long-span, prestressed concrete bridges.

We'll start with the basic approach to prestressing, as illustrated in Fig. 1.

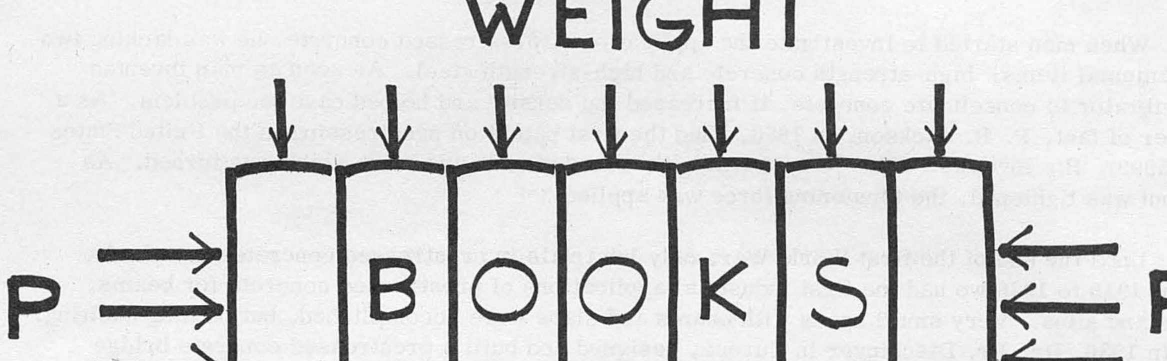

FIGURE 1.

If you try to pick up a set of encyclopedias from a table without much force on both hands, you probably will lose all the books, however, if you increase the pressure, these books will stay put and not fall down--considering the span.

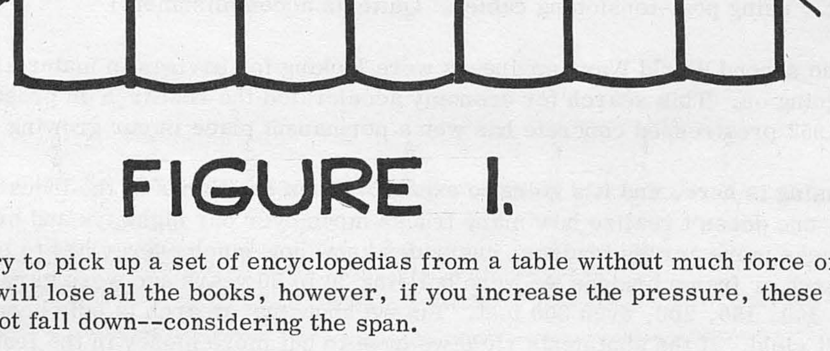

FIGURE 2.

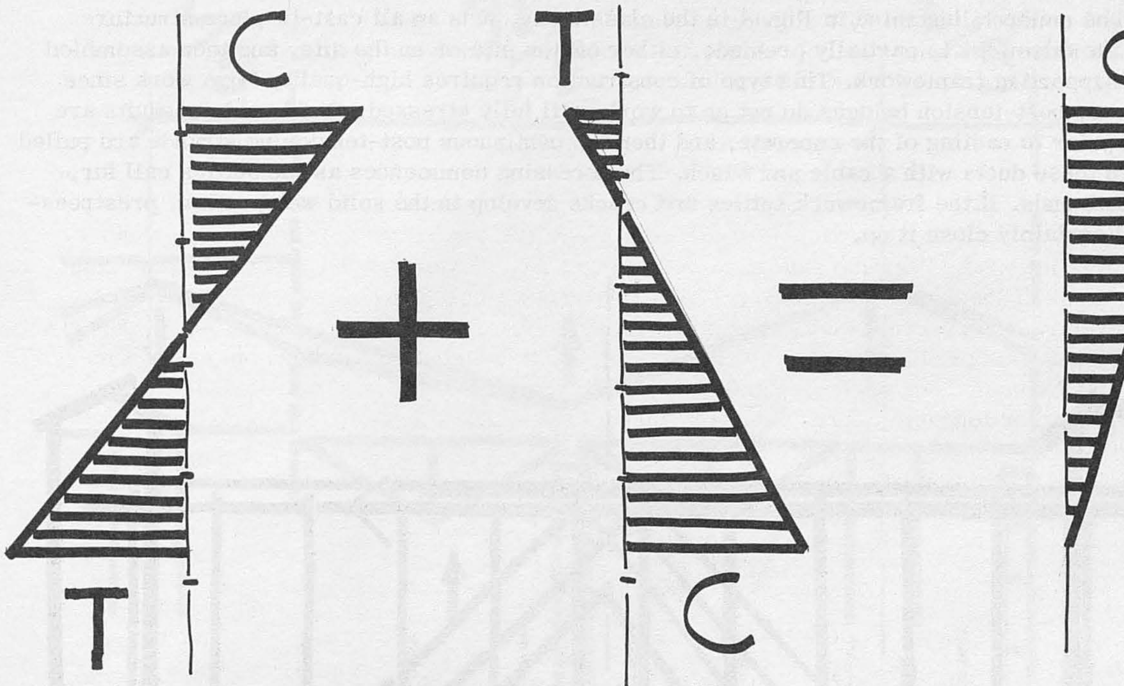

FIGURE 3.

Figures 2 and 3 show how energy is developed through mechanics in a prestressed concrete beam.

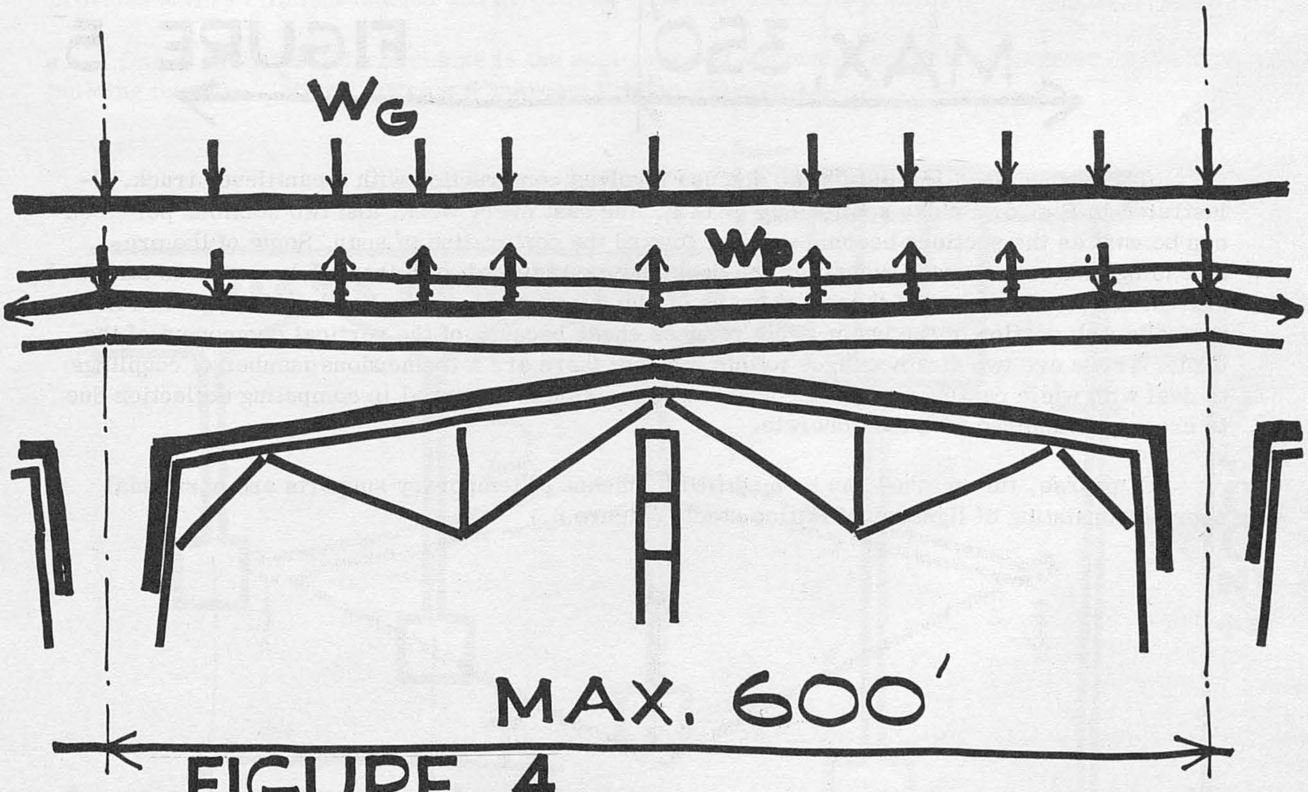

FIGURE 4.

The method illustrated in Fig. 4 is the classic one. It is an all cast-in-place structure where the falsework is partially premade, either off the site or on the site, and then assembled on the supporting framework. This type of construction requires high-quality form work since long span, post-tension bridges do not go to work until fully stressed. Rigid cable conduits are placed prior to casting of the concrete, and then the continuous post-tensioning strands are pulled through these ducts with a cable and winch. The stressing commences as the statics call for, from both ends. If the framework settles and cracks develop in the solid web portion, prestressing will certainly close it up.

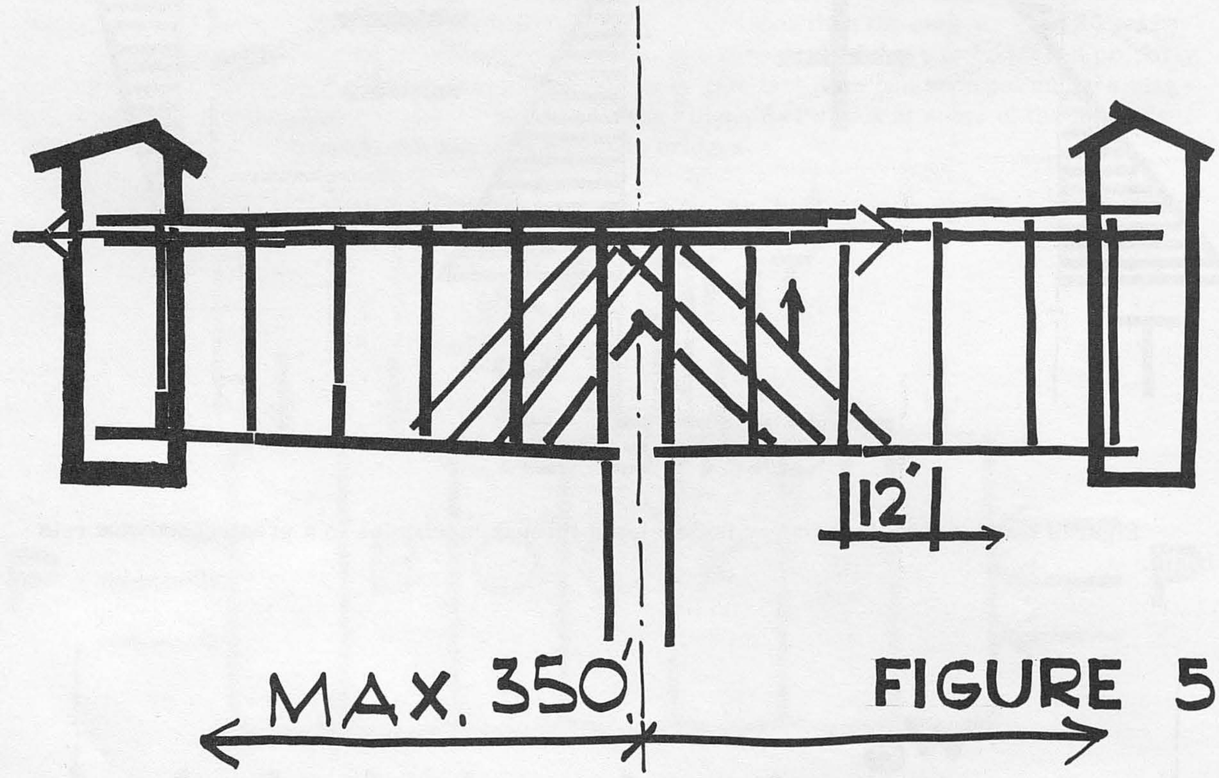

FIGURE 5.

The next method I would like to discuss involves construction with a cantilever truck, illustrated in Fig. 5. Bridge sections up to 12 ft. are cast every week, and two sections per week can be cast as the sections become smaller toward the center-line of span. Some of the prestressing tendons run continuously in the deck slab as required, and then each section is stressed against the previous one. If there are spans of 600 ft. or more, an inclined cable is placed in the solid web portion of the beam. This reduces shear because of the vertical component of the cable. There are two disadvantages to this method: there are a tremendous number of couplings to deal with while casting the bridge deck, and precision is essential in computing deflection due to creep encountered with the concrete.

Of course, this method can be modified by means of temporary supports and horizontal shoring consisting of lightweight lattice steel. (Figure 6.)

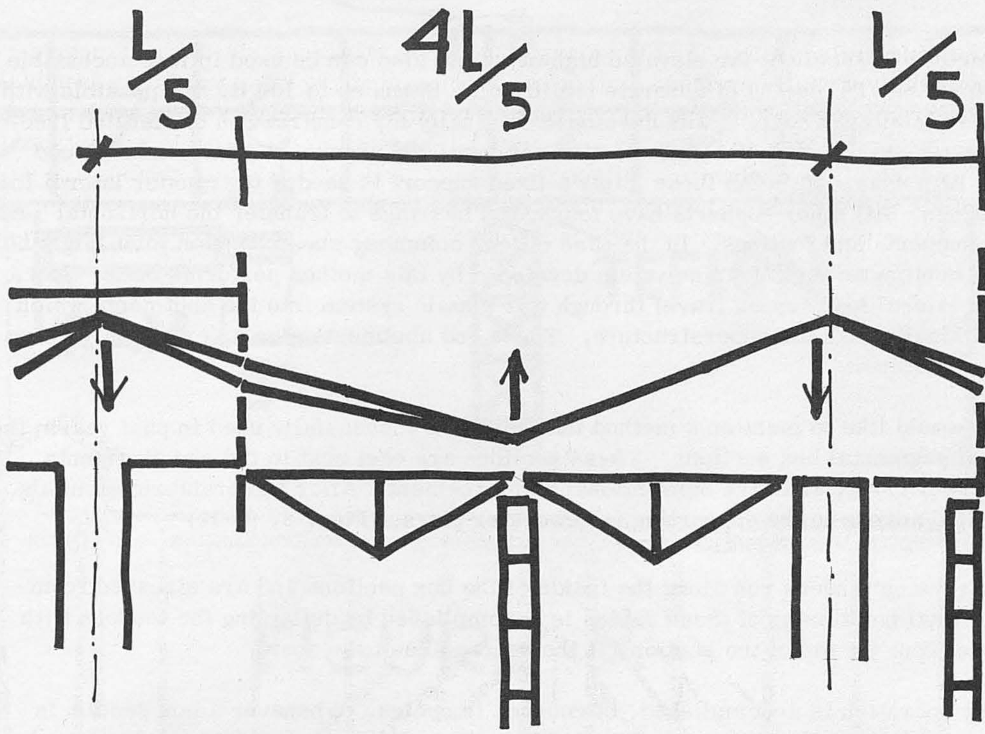

FIGURE 6.

A rig can permit casting the entire length of a span. The continuous post-tension cables are spliced at the fifth point of the span and flared out to allow easy coupling of tendons. This provides a very efficient method and gives true continuity in the structure.

One of the latest developments is the application of a movable scaffolding carrier or "bridge building machine," which forms a mushroom bridge. (Figure 7.)

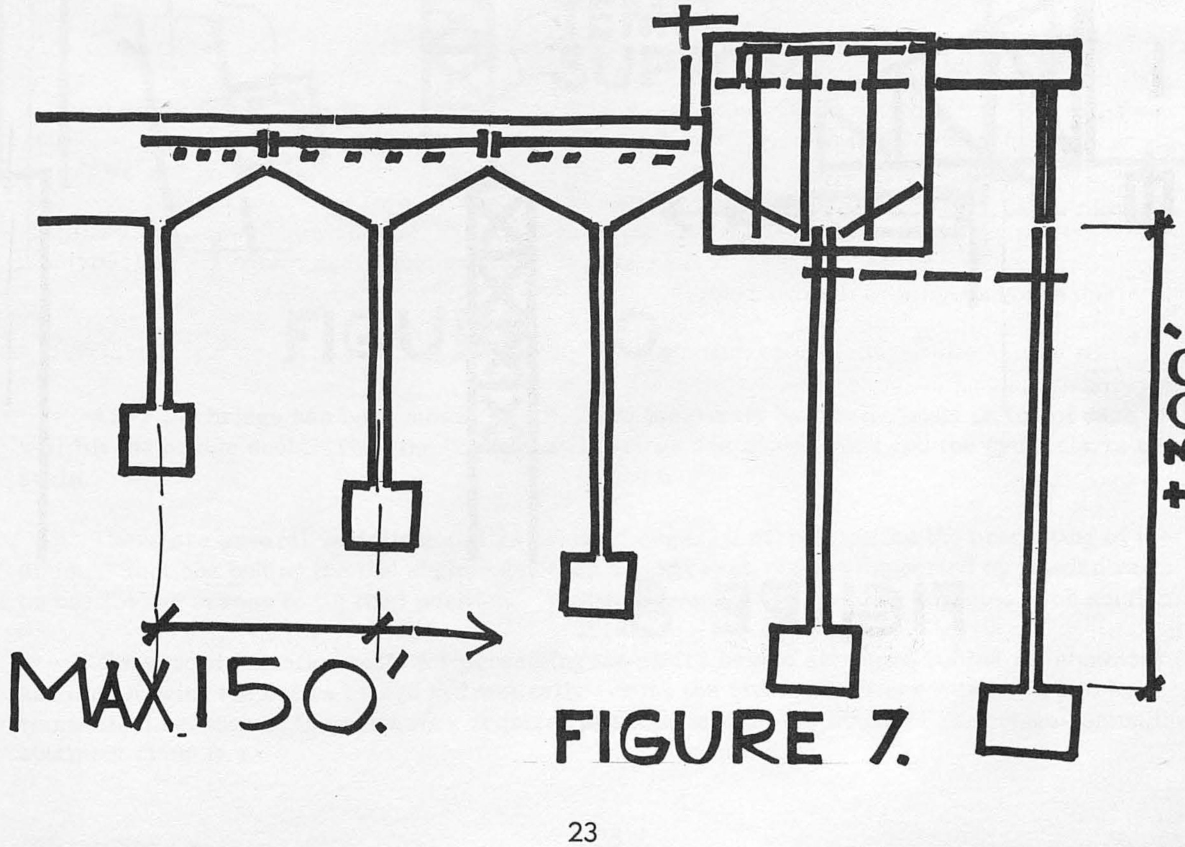

FIGURE 7.

This forming method is excellent for elevated highways, but also can be used in less accessible terrain where forming and placing of concrete is difficult. Spans up to 100 ft. are possible with this method. As a matter of fact, it was developed originally for construction of elevated freeways through towns. In the case of short and stiff columns, the expansion joint can be placed every fourth or fifth span. Between these joints a fixed support is needed to transfer lateral load down to the footings. All other supports have four-point bearings to transfer the horizontal forces into the supports and footings. In the case of long columns, one expansion joint might be sufficient. The continuous rigid frame system developed by this method performs better than a hinged one. All lateral load forces travel through this elastic system into the abutments which are cast monolithically with the superstructure. These end abutments give an excellent torsion stability to the structure.

Finally, I would like to mention a method that has been successfully used in past years; the prefabrication of segmental box sections. These sections are cast next to the end abutments. They are about 30 ft. long, and have conventional reinforcement. After the prefabrication, the sections are pulled across to the supporting falsework or piers. (Figs. 8, 9, 10)

The prestressing tendons run along the inside of the box sections and are stressed from both ends. The final positioning of these cables is accomplished by deflecting the tendons with high tensile rods from the top of the sections at the center line of the span.

The entire operation is accomplished, of course, in cycles. Whenever a box section is finished it is moved toward the other end of the bridge. The sliding is done on stainless steel plates, approximately two ft. wide and six ft. long, positioned on top of the permanent and temporary piers. The bridge itself rides on doughnut-shaped boxes, each box containing a 2-inch-thick neoprene pad which replaces the oil in the "hydraulic" system. On top of the neoprene pad is a steel plate coated with teflon. Increasing the load on the teflon decreases its coefficient of friction.

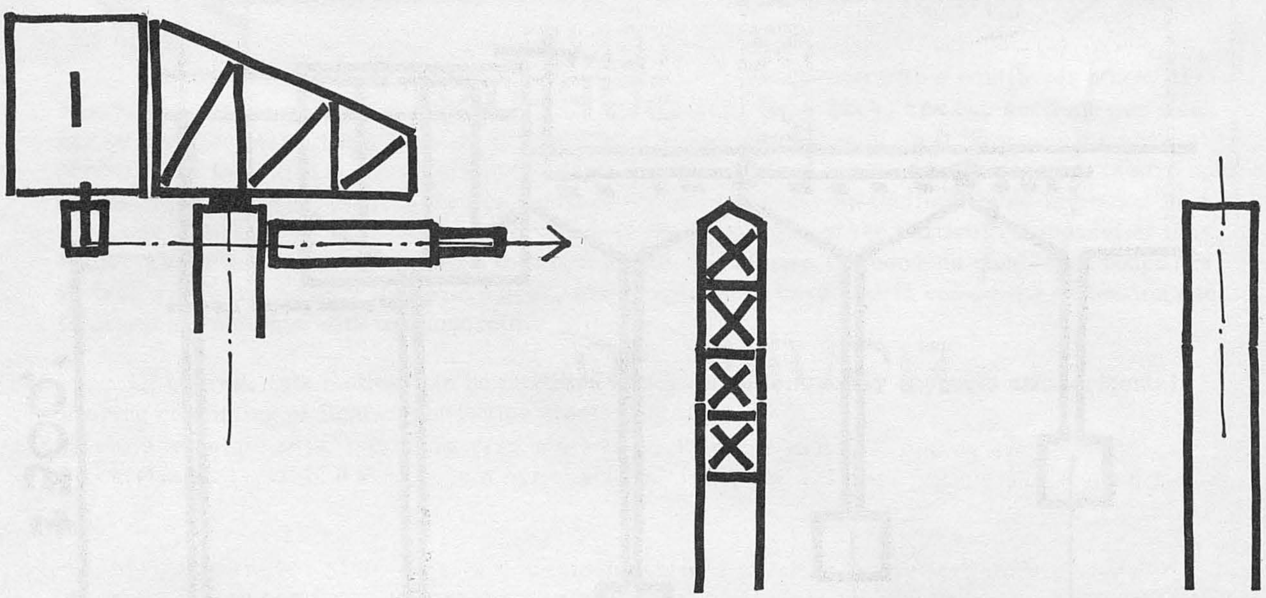

FIGURE 8.

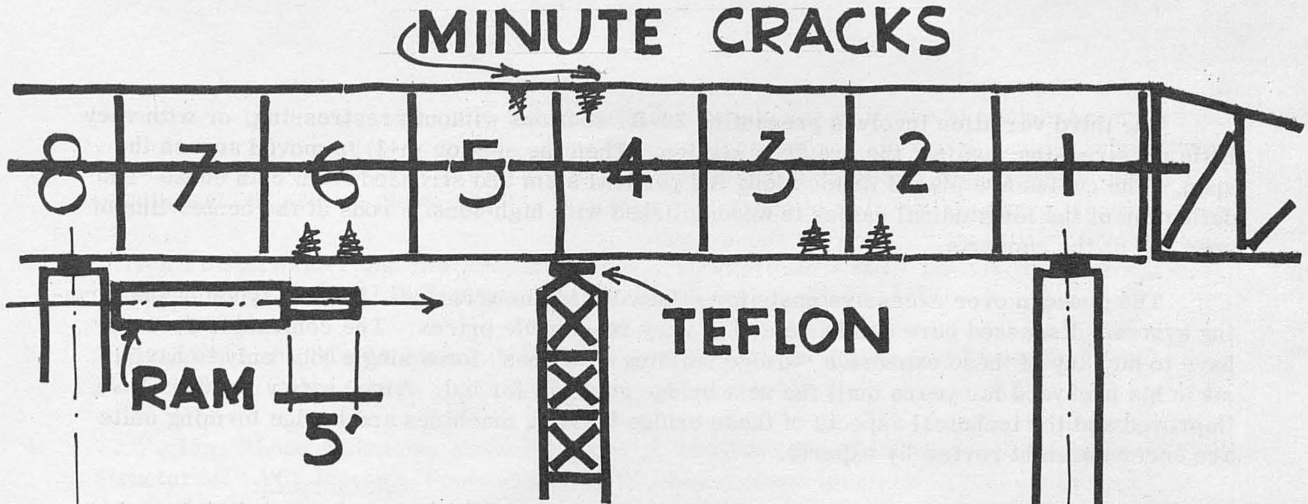

FIGURE 9.

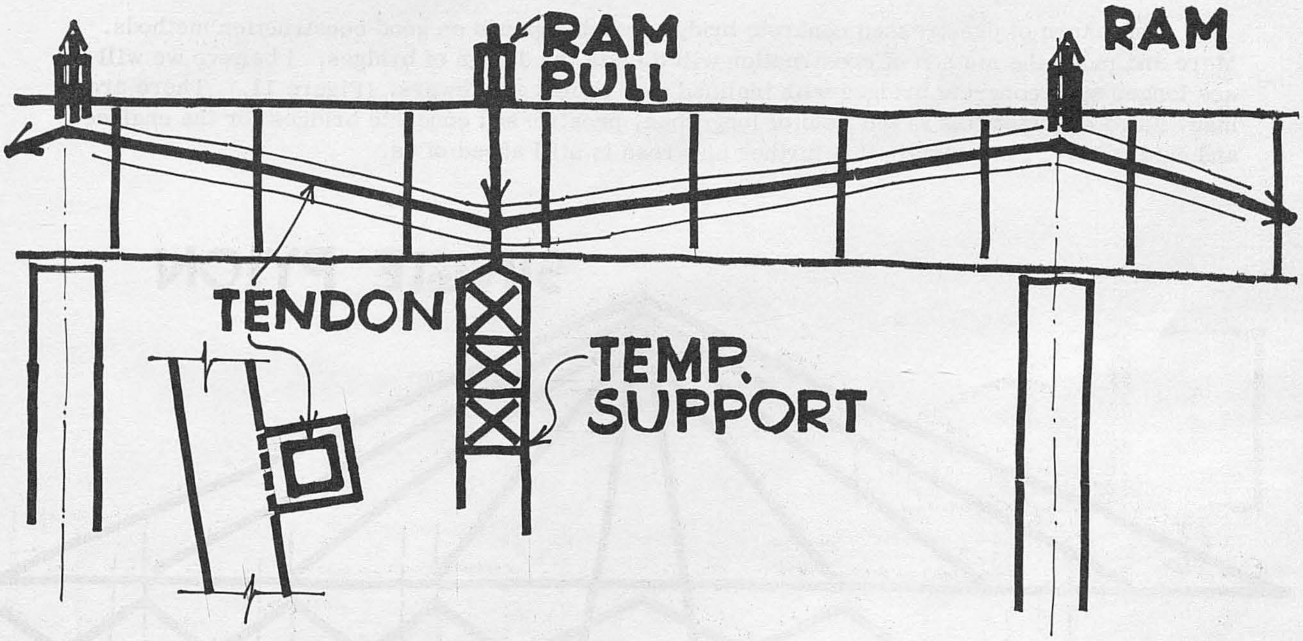

FIGURE 10.

After the bridge has been moved five ft., two temporary hydraulic jacks on top of **each pier** will lift the bridge deck. Then the "doughnut" bearings are moved back and the cycle starts over again.

There are several variations of this bridge design. It started out by the precasting of individual sections behind the end abutments, then moving each section supported by wooden rails on scaffolding across to its final position. A cast-in-place 12 in. portion connects each section.

The second variation calls for precasting the entire bridge structure behind the abutment and then moving the entire bridge hydraulically across the river. At times this proves to be less economical because of the earthwork required to accommodate the length of the bridge behind the abutment (1500 ft.).

The third variation involves precasting 30-ft. sections without prestressing, or with very little prestressing, against the previous section. Then the section (n+1) is moved across the span. The cables are placed inside along the vertical stem and stressed from both ends. The deflection of the longitudinal cables is accomplished with high-tensile rods at the center line of span and at the supports.

The concern over excessive costs for falsework is unwarranted. Several types of the forming systems discussed here can be rented at very reasonable prices. The contractor does not have to buy any of these expensive "bridge building machines" for a single job, only to have it sit in his backyard for years until the next bridge goes out for bid. Also, safety features have improved and the technical aspects of these bridge building machines and bridge forming units are under constant review by experts.

In the United States the number of long-span, prestressed concrete bridges is increasing. Bridges up to 550 ft. clear span are in the design and planning stages, but a word of caution is in order. In the coming years only a few individual solutions for long-span bridges will be economically feasible. If we have to resort to shorter spans, let's not put a forest of piers underneath the deck, or use many beams or diaphragms. Let's use our imagination in the design and construction of aesthetic concrete bridges. Also, the best ideas of a bridge engineer won't help the design if the contractor is not ready to execute them at the job site. There has to be a link between the designer and the contractor in order to develop a steady cooperation in solving details during design and construction.

The future of prestressed concrete bridge design depends on good construction methods. More and more the method of construction will dictate the design of bridges. I believe we will see longer span concrete bridges with inclined stay cables and towers. (Figure 11.) There are many more opportunities in the field of long-span, prestressed concrete bridges for the engineer and contractor. I am certain that further progress is still ahead of us.

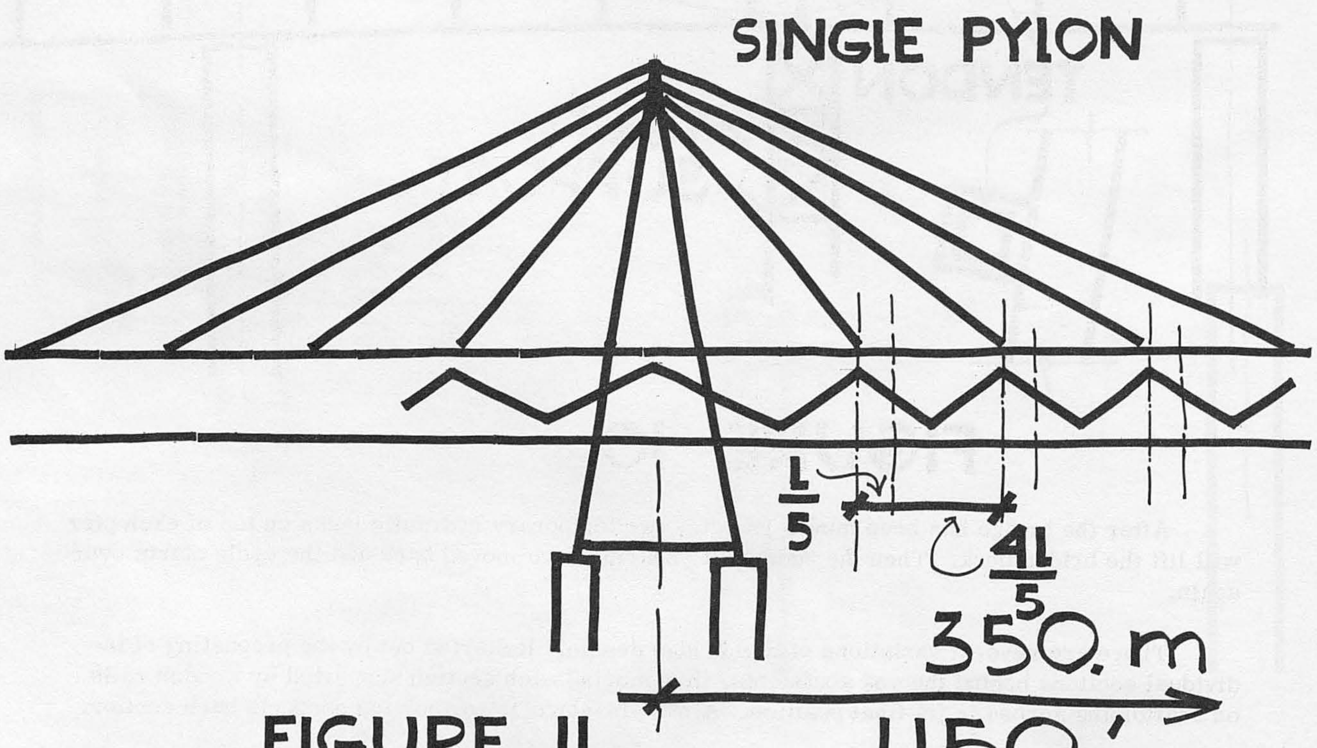

FIGURE 11.

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