CAE | Spring 2023 | Seminar

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March 31, 2023

Reinventing ~~the wheel~~
- stronger, lighter, faster -
UHPC Structural Design

Presenter: Steven Nolan, P.E.

Senior Structures Design Engineer

Florida Department of Transportation

FDOT

Reinventing… with UHPC Structural Design

Speaker Bio: Steven Nolan, P.E.

Steve has been a registered Professional Engineer in Florida since 2001. He received his engineering degree from the University of New South Wales, Sydney Australia in 1989. He worked as a Construction Engineer for a heavy civil contractor before emigrating to the USA in 1996, and joining the Florida Department of Transportation (FDOT).

He currently leads the implementation of novel structural materials for bridge applications within the Florida DOT State Structures Design Office. These materials currently include 10 technologies of interest including UHPC, FRC, and various FRP composite reinforcements which Steve coordinates as Chair of the statewide Structural Advanced Materials Technical Advisory Group (SAMTAG).

Steve’s 26 years with FDOT includes: in-house bridge design analysis and detailing, standards and specifications development, design policy refinement, and technical training development and delivery.

Reinventing… with UHPC Structural Design

Speaker Bio: The "REAL" Steve

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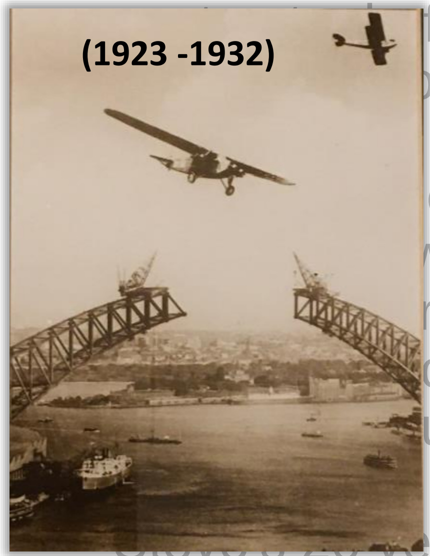
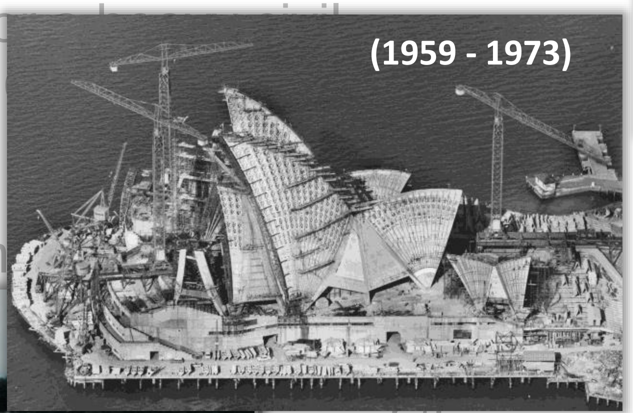
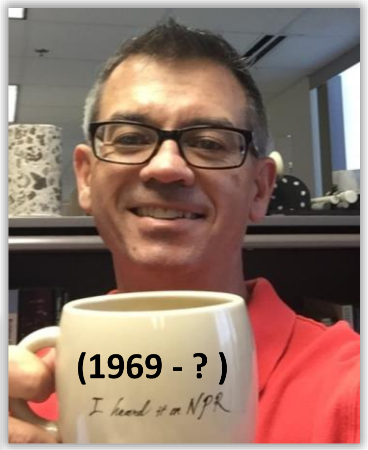

(1923 -1932)


(1959 - 1973)


(1969 - ?)


(1939 - 2014)


(1991 - 1992)

(1994 - 1996)

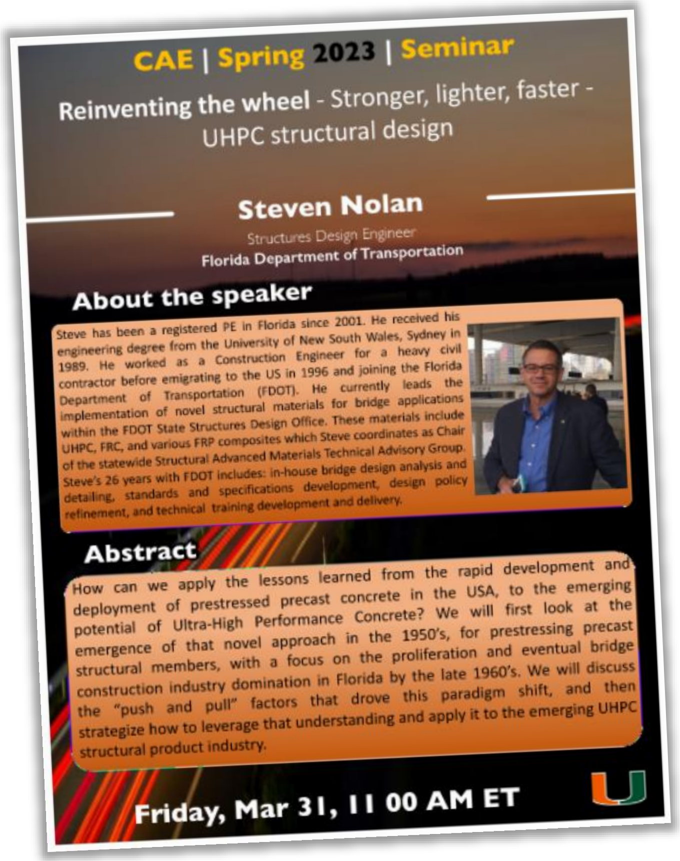

(1993)

Reinventing… with UHPC Structural Design

ABSTRACT

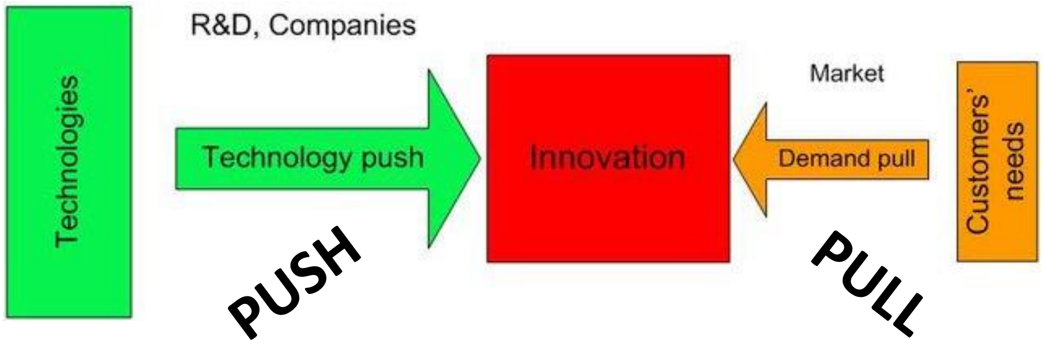
How can we apply the lessons learned from the rapid development and deployment of prestressed precast concrete in the USA, to the emerging potential of Ultra-High Performance Concrete?

- We will first look at the emergence of that novel approach in the 1950’s, for prestressing precast structural members, with a focus on the proliferation and eventual bridge construction industry domination in Florida by the late 1960’s.
- We will discuss the “push and pull” factors that drove this paradigm shift.
- Then strategize how to leverage that understanding and apply it to an emerging UHPC structural product industry.



Outline

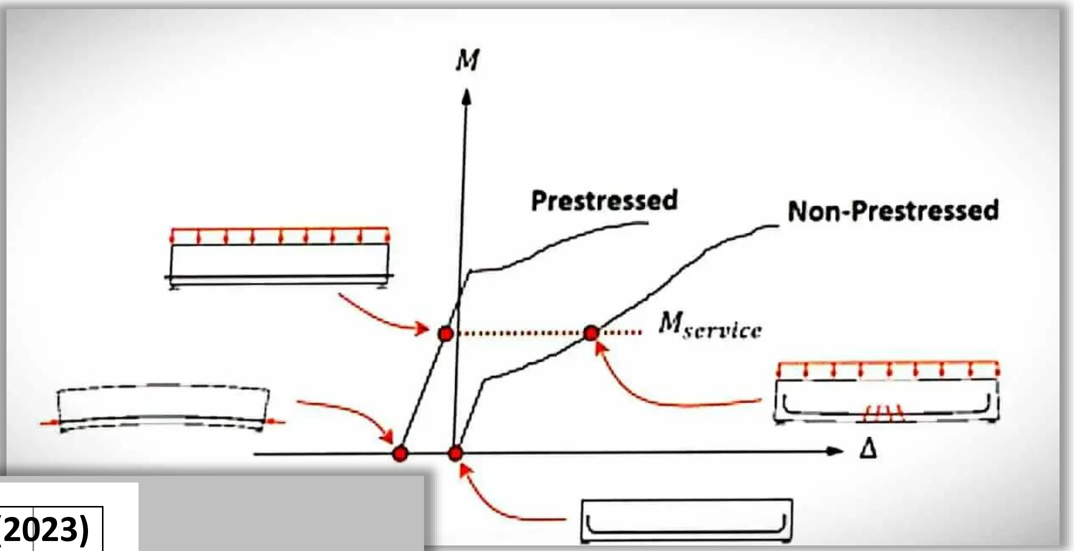
- Development of the Prestressed Concrete (PC) in Florida
- What is so great about UHPC ?
- What are the real needs?
- How do we apply any lessons learned from PC success?
- What are the near-term opportunities for UHPC structural design

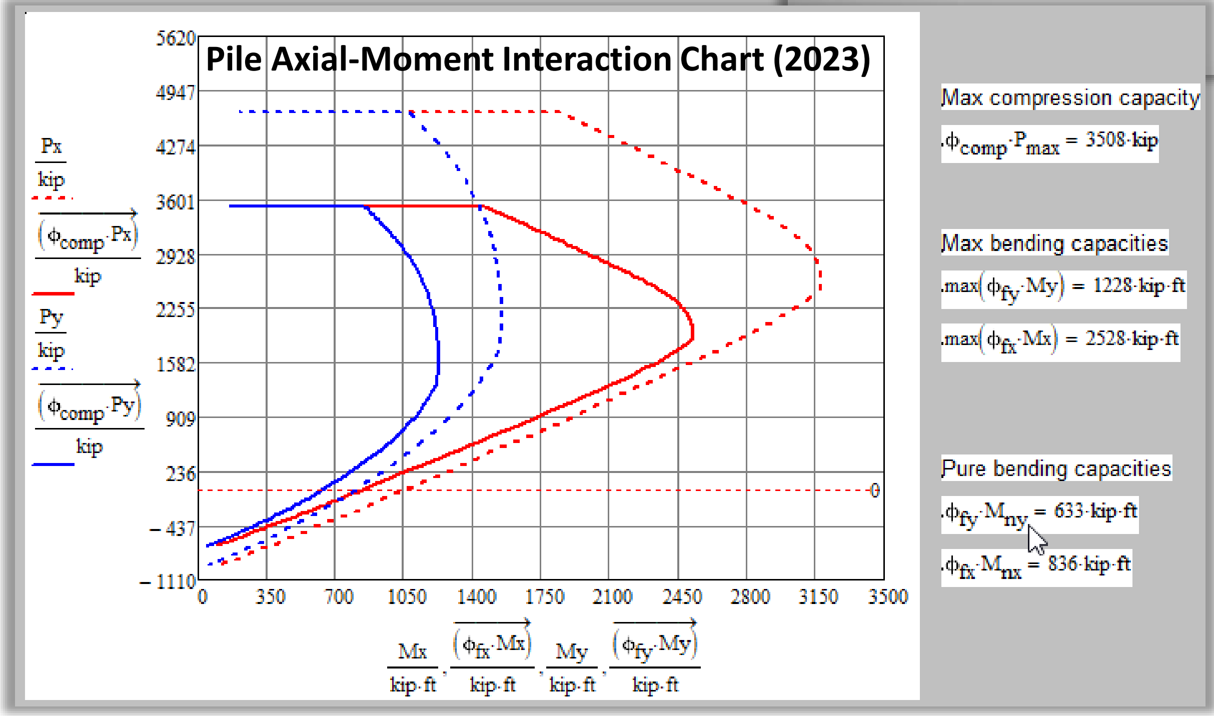


Prestressed Concrete (Pull & Push Factors)

Some obvious advantages of prestressing concrete for bridge members:

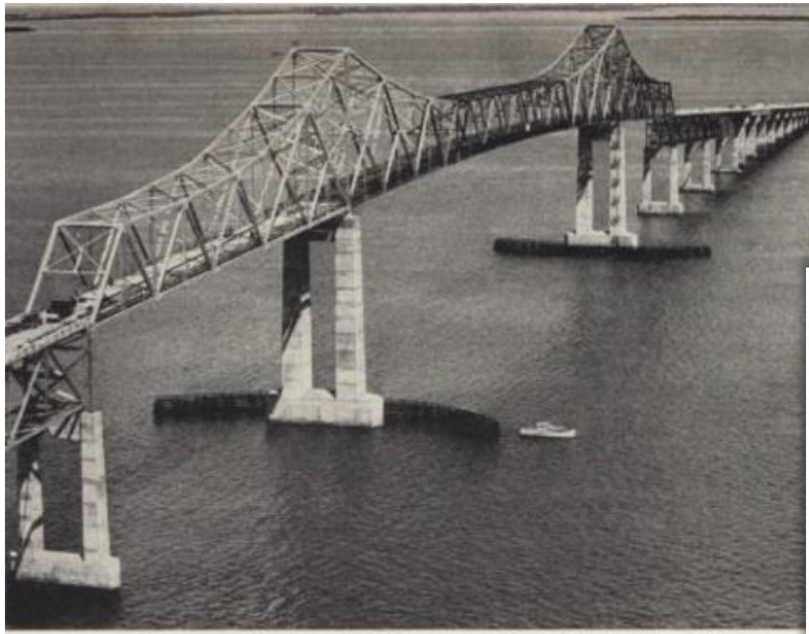
- Longer beam spans = fewer foundation units
- Thinner sections = less materials & handling costs
- Faster Fabrication
- Durability ?
- Aesthetics ?





Prestressed Concrete Development in Florida

1st Sunshine Skyway (1950-1954) & Gustave Magnel



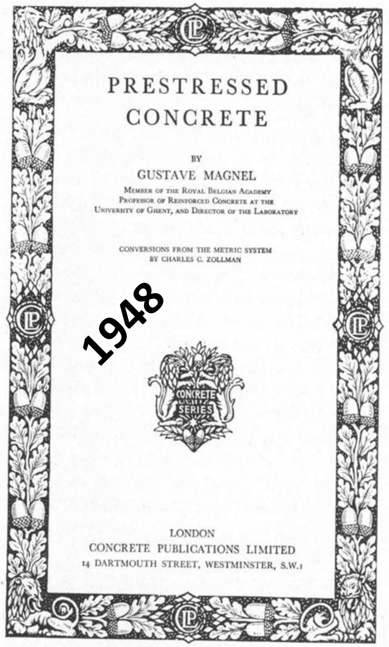
View Looking Northwest across the High-level Portion of Structure C

Gustave Magnel

Philosopher • Teacher • Builder

(1889-1955)

People who personally knew Professor Gustave Magnel or were present at his lectures all readily agree on one thing about the man—that he was one of the most effective teachers of his time. Here in slightly edited form



PRESTRESSED CONCRETE

BY

GUSTAVE MAGNEL

MEMBER OF THE ROYAL BELGIAN ACADEMY
PROFESSOR OF REINFORCED CONCRETE AT THE UNIVERSITY OF GHENT, AND DIRECTOR OF THE LABORATORY

CONVERSIONS FROM THE METRIC SYSTEM BY CHARLES C. ZOLLMAN

CONCRETE SERIES

LONDON
CONCRETE PUBLICATIONS LIMITED
14 DARTMOUTH STREET, WESTMINSTER, S.W.1

1948

Fig. 8. The first edition jacket of Professor Magnel's book in English on "Prestressed Concrete."

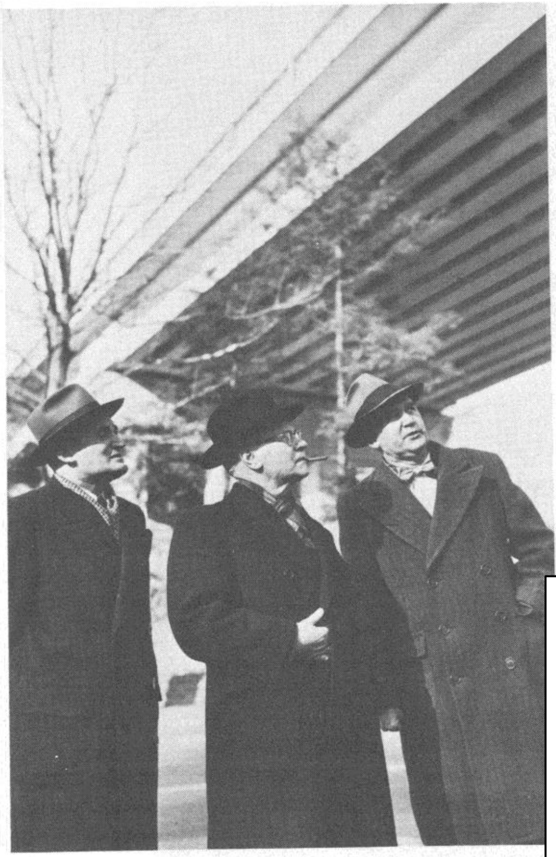


Fig. 19. A year before Magnel's death, the Professor (center) admires the Walnut Lane Bridge with Charles Zollman (left) his former student and good friend, and Samuel Baxter (right).

Walnut Lane Memorial Bridge
(Philadelphia, PN)
1st prestressed girder bridge in USA (1951)

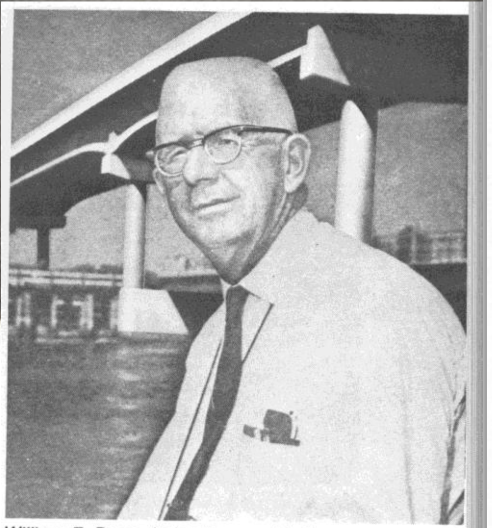
Prestressed Concrete Development in Florida

1st Sunshine Skyway (1951-1954) & William "Bill" Dean

View Looking Northwest across the High-level Portion

1946 *Bidding attempt exceeded budget with RC*

1951 *Redesigned with PC Beam option*



William E. Dean. In background is the Sebastian Inlet Bridge for which Dean received a special PCI Award in 1964.

Florida SRD Chief Bridge Engineer (1909 – 1965)

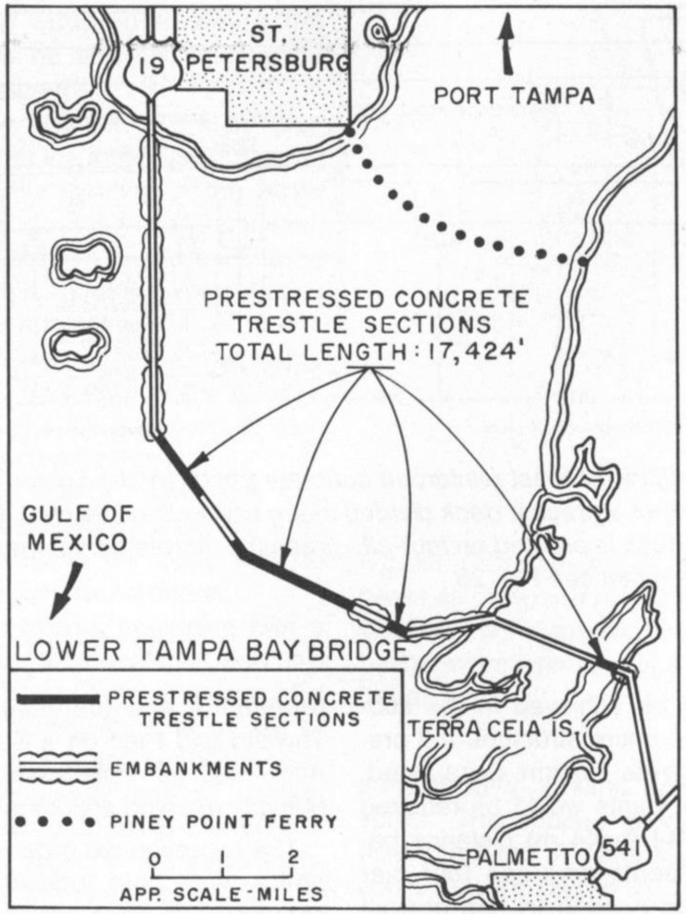


Fig. 21. Location map of Lower Tampa Bay Bridge.

Fig. 2. Pictured is Eugene Freyssinet.

French Structural Engineer (1879 – 1962)

Prestressed Concrete Development in Florida

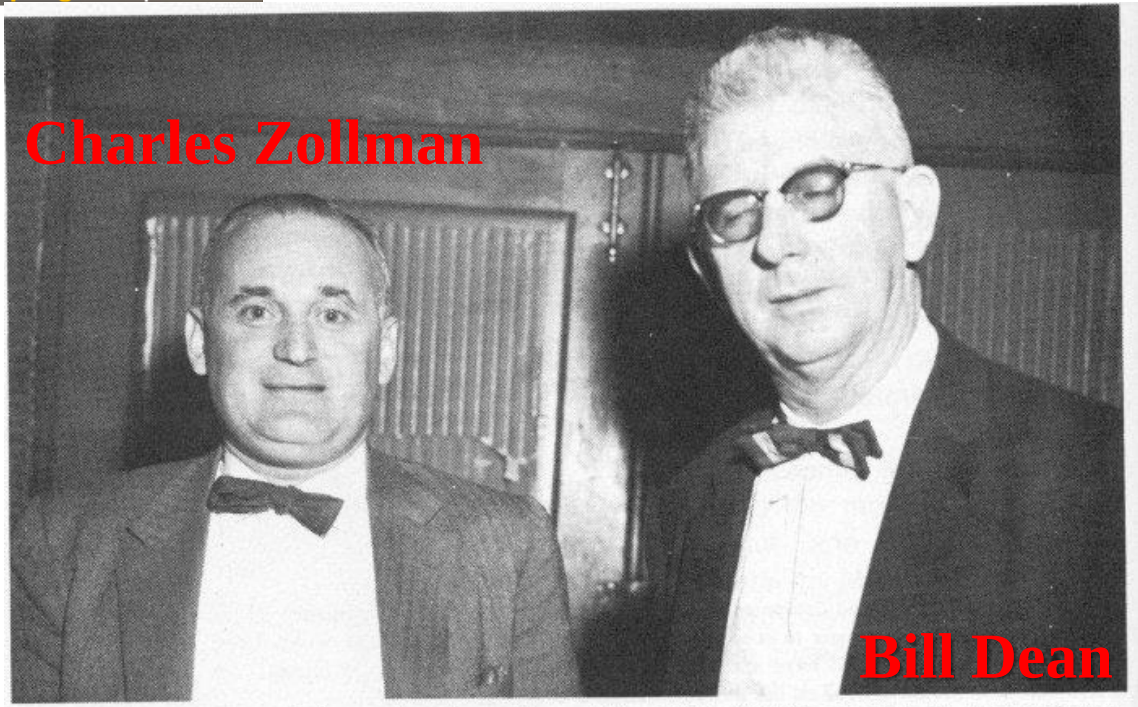
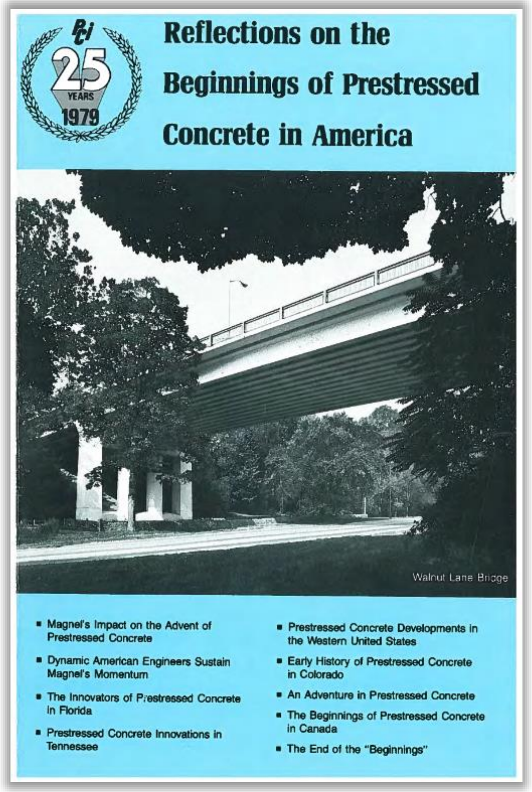


Fig. 28. Bill Dean and the author together at the 1955 PCI Course in St. Petersburg, Florida. During Dean's last years his eyesight was failing.

PCI's First National Prestressed Concrete Short Course, (St. Petersburg, FL)

October 10-12, 1955



1981 Compilation of PCI JOURNEL, Vol. 23, No. 3 May/June 1978 and successive issues through Vol. 25, No. 3 May/June 1980.

Reading Suggestion: Bill Dean's paper titled:
"Outlook to The Future of Prestressed Concrete"

https://www.pci.org/PCI_Docs/About/25YRBPCA.pdf

Prestressed Concrete Development in Florida

OUTLOOK TO THE FUTURE OF PRESTRESSED CONCRETE*

By William Dean†

The title of this paper would indicate a clairvoyant ability on my part for which I make no claim. In some twenty-five years of engineering practice I have had little experience with the use of crystal balls, tea leaves or Zodiacal science.

In recent years the prediction of future trends in developments has become a highly specialized field in business management that has important branches in engineering. While I have little detailed knowledge of the methods employed by scientific prognosticators, the general procedure seems to be a process of collecting data on trends as they have developed in the past, drawing curves from past through present and then by extrapolation projecting these curves into the future and attempting to draw conclusions therefrom.

This general procedure is a very important part of traffic engineering. In the planning of modern highway facilities recognition of probable future traffic problems, five, ten, twenty or more years in the future, is a necessary part of the design if further obsolescence is to be avoided. Traffic engineers have been quite successful in predicting general trends; however, in the matter of actual volume at some future date all these predictions very often underestimate by a considerable amount. Highway traffic is developing at an accelerated rate, and quite often the slope of the curve representing future traffic is considerably steeper than predicted. Prediction of future requirements for ten years are often reached in less than five. Demand is often increasing faster than any past experience would indicate.

Having watched the development of prestressed concrete for the past several years, I wonder if a condition somewhat analogous to this traffic problem does not exist in the field of prestressed practice. Certainly we can say that five years ago there existed much interest in prestressed work, and there were strong indications of considerable development in the field. However, I wonder how many of us foresaw the rapidity with which the development would come about.

It is just a little over five years since Charlie Zollman made his first visit to my office in Tallahassee to discuss a possible design for use on the trestle portion of the Sunshine Skyway. Up until that time Charlie was the only engineer with any reliable information and experience in prestressed concrete that I had met; although, I had met quite a number of them that were quite inexperienced and grossly misinformed.

As a result of some of those other meetings, I must confess, as Charlie told you all this morning, that I had considerable prejudice, but I will not admit that Charlie sold me anything. He showed me by fact and by reason, and as an outgrowth of that first visit to my office, in April of 1950, the design was developed for the trestle portion of the Sunshine Skyway which did have a very important part, I think, in furthering prestressed practice in this country. I can say that Charlie introduced me to prestressing. It is something for which I will always have a warm spot in my heart and much gratitude.

We are now concluding a three-day conference designed to further prestressed practice. It has been my pleasure to attend and participate in several such conferences, and as an indication of trend we might look back

*This paper is reprinted from PCI's First National Prestressed Concrete Short Course, presented at St. Petersburg, Florida, October 10-12, 1955.

†Chief Bridge Engineer, Florida Highway Department, Tallahassee, Florida.

Written 23 years ago, many of the concepts Dean talked about are still relevant today.

and examine some of the principal developments associated with these gatherings.

The engineering profession and construction industry had a significant introduction to prestressed practice at the First United States Conference on Prestressed Concrete held at Massachusetts Institute of Technology in the summer of 1951. The sponsors of this conference had hoped for a registration of 200 to 300. Actual registration was more than twice the anticipated number. Attendance included teachers and students of structural engineering, practicing engineers, prospective manufacturers of materials for prestressing, proponents and patent holders of certain prestressing methods and a representation from the construction industry.

At that time the first major prestressed bridge in the United States, the Walnut Lane Bridge at Philadelphia, was about complete, and a few smaller bridges and structures had been built or were under process of construction in other parts of the country. Papers given at this conference described construction in the United States up to that time; however, many of the constructions described were of European structures. Valuable data on the properties of material for prestressing were given by manufacturers who were naturally looking for markets, and considerable factual data on design concepts and methods were presented.

The general air of most attendants was one of intense interest with a generous portion of skepticism. The experience of one of the contributors, with whom I am well acquainted, might be cited. With considerable brashness, and against all rules of discussion, he accepted an assignment to discuss certain theoretical and practical design concepts. A paper was conceived in ignorance, written out of a vast background of inexperience and delivered in an attitude involving approximately equal parts of interest and cautious skepticism.

Despite its amateurish nature some basic problems, as they appeared at the time to one average practicing engineer, were listed. Some of these were lack of: simple practical method of linear prestressing, freer patents, authentic design criteria, authentic test of large scale members on which the design criteria might be based and only a limited number of reliable construction firms with experience in prestressing. The past four years has seen presently acceptable solutions to every one of these problems.

The next conference that might be remembered was a part of the Centennial of Engineering in Chicago in the Fall of 1952. Prestressing was given a very important part on the program. Interest was such that the session on prestressing had to be moved from the original scheduled meeting place to the largest ballroom of the Conrad Hilton Hotel and even there late comers had to be satisfied with standing room only. In the year immediately past the contract had been let for the structures on the Sunshine Skyway totaling 363 trestle spans with precast, prestressed concrete girders. At the time this was the largest contract for prestressed members ever let in any part of the world.

Since that time the Skyway construction has been very considerably exceeded in other big contracts. You just saw an example of that presented by our last speaker. Now, this same brash contributor whose efforts at the MIT conference has been described was again in attendance. This time, with an increase in enthusiasm and a considerable reduction in skepticism, he described test to destruction of full size members being used on the Skyway. These tests had shown

from the construction and materials industries form inseparable and interrelated parts. Major advancement without the proper contribution

if we are to keep abreast of structural practices, we have no choice in the matter. Prestressing as an accepted construction

method is here with us. Accepting this as a fact, it behooves all of us to learn how to live with it, to learn its applications together with its limitations.

At several points in this paper reference has been made to significant advances and developments. Certainly any mention of these would be lacking if the *Criteria for Prestressed Concrete Bridges*, published by the United States Bureau of Public Roads, was omitted. While these criteria were developed principally to govern highway bridges, they are laws that are applicable to prestressing in general. Most engineers very properly look askance at any radically new technical development until it has been subjected to exhaustive test, tried in the light of experience and suitable rules for its use are developed.

Some two years past, a joint committee of two of the major technical societies of the country was set up to develop a code for prestressing. The establishment of this proposed code by this committee has been delayed for various reasons, and in the meantime prestressing is so logical and practical and has aroused such wide interest that construction would not wait for the development of the code. In order to achieve uniform practice in highway bridges, the Bureau sought out and sorted a composite of the most informed opinions and presented their criteria to the engineering and construction industry.

There is hardly any way to measure the importance of this booklet to the development of prestressing practice. Many engineers who are hesitant, or in doubt as to the proper applications, unit stresses, design concepts and so forth, have been reassured by knowing that an organization having the well deserved prestige of the Bureau, with its background of careful, conservative practice, has officially approved prestressed construction. The *Criteria*, where possible, will be revised and improved from time to time; however, as presently published, they can be used with the assurance that structures designed in accordance with their specification will produce serviceable, practical structures with adequate margins of safety.

So far, we have been looking backward and touched on a very few high spots in the advancement of prestressed concrete from a logical and interesting theory of a few years past to the practical and generally recognized construction method of today. Perhaps the trend that has been shown has been sufficiently evident to warrant a little prognostication. It does not seem that we would need any crystal ball, tea leaves or other impedimenta and paraphernalia of the occult art to say that prestressed concrete has earned a permanent place in American construction practice. It is not going to supplant the older and universally accepted construction methods in reinforced concrete, steel or timbers, but it does add another type from which a choice can be made. While prestressed concrete will not supplant conventional construction types, there are many applications where it can be expected to do a better job, and in these applications it will certainly take over. To try and list these applications would be pointless. It would seem sufficient to say that as hundreds have been found in the past, thousands will probably be found in the future.

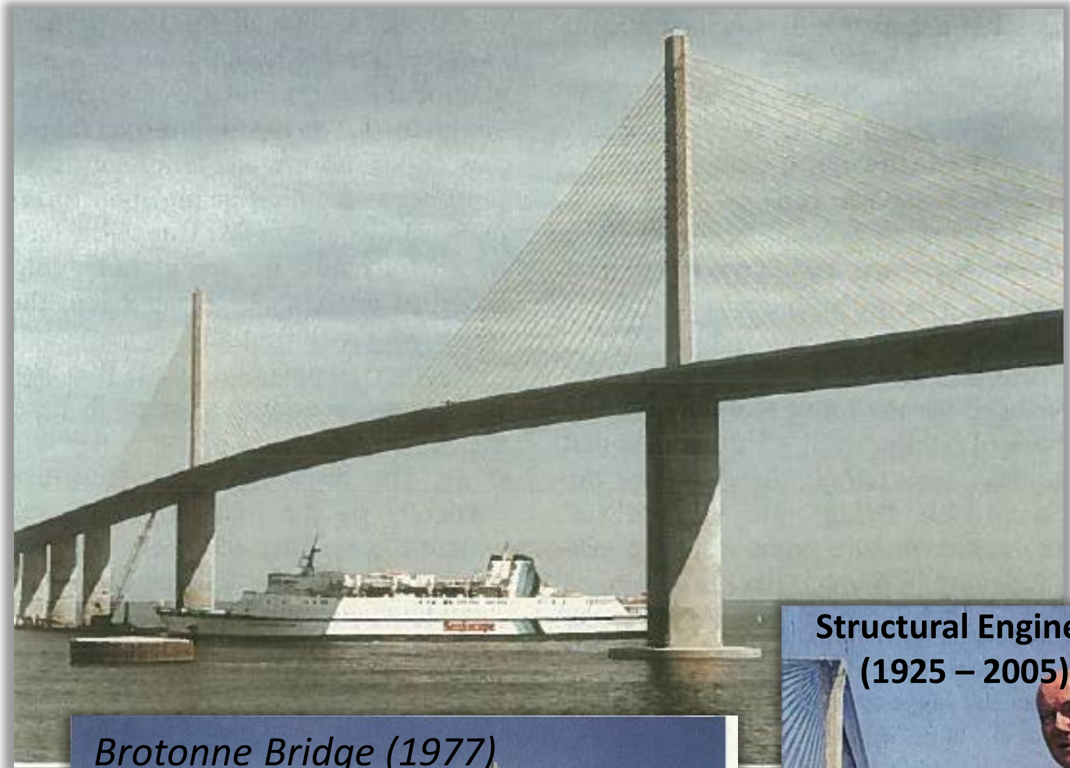
Getting back to that MIT conference and that amateurish paper by the rash contributor, about the only statement with any degree of sagacity, and that only a simple truism, was the following concluding statement: "When we learn to build as good a structure as we are now building at a reduction in cost or a superior structure for the same cost, prestressed construction is sure to gain a wide acceptance in American structural practice." The conditions set forth in this four year old statement have been fully met, and the predicted acceptance has been realized.

In concluding it might be appropriate to observe that all of us who expect to make a living in structural work, whether we belong to the academic group, practicing engineers or the construction industry, will do well to learn as much as possible about prestressing, its design, its applications, construction methods and limitations, for if we are to keep abreast of modern practice, we will be dealing with the subject of prestressed concrete for the rest of our careers.

Courtesy: PCI Journal "25 Year Reflections on the Beginnings of Prestressed Concrete in America (*1981).*

Prestressed Concrete Development in Florida

2nd Sunshine Skyway (1984-1987)



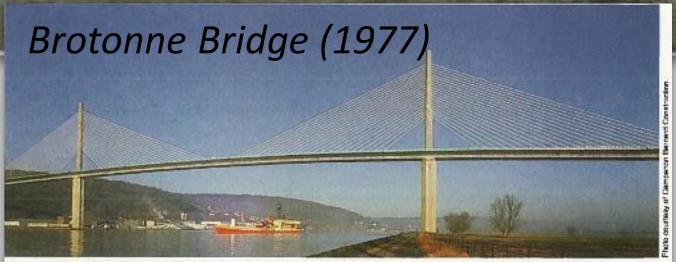


Fig. 13. The Brotonne Bridge is pictured over the Seine River in France.

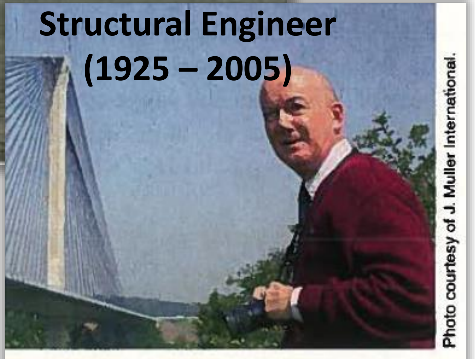
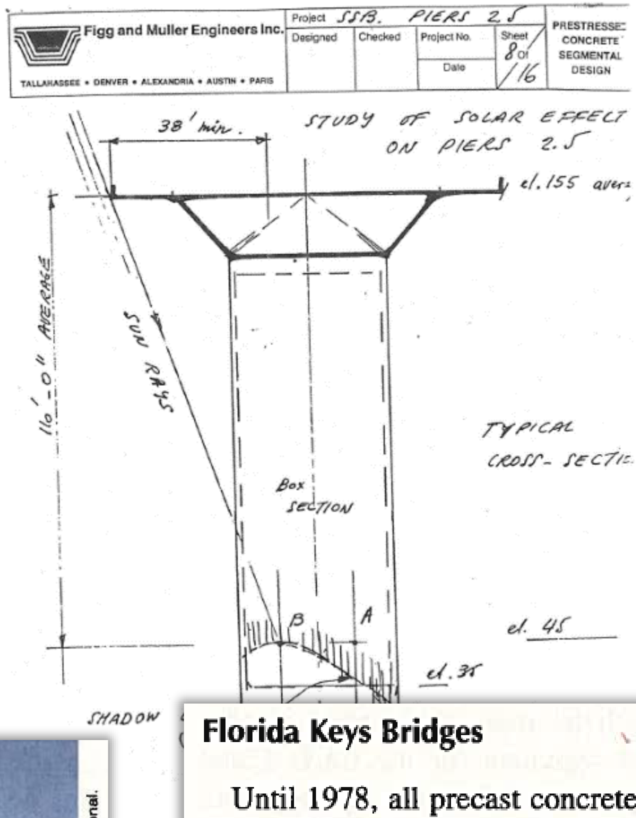
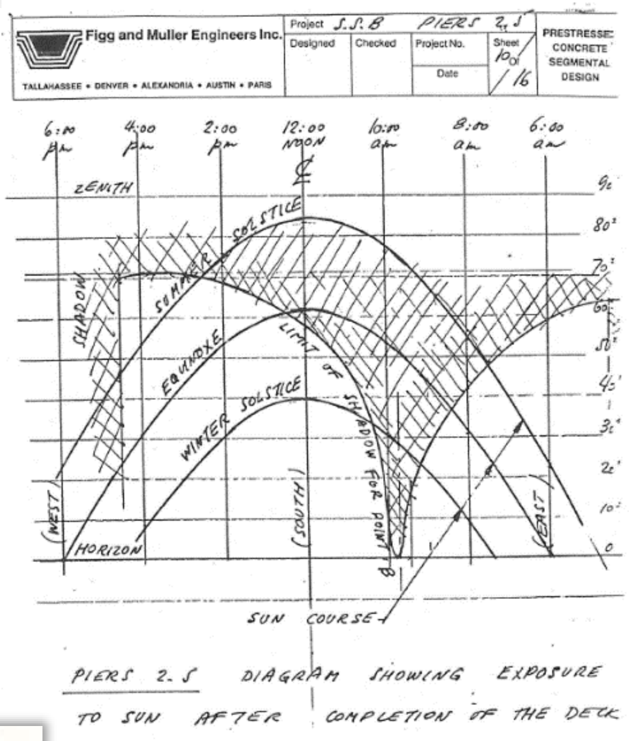


Fig. 1. Pictured is Jean Muller.





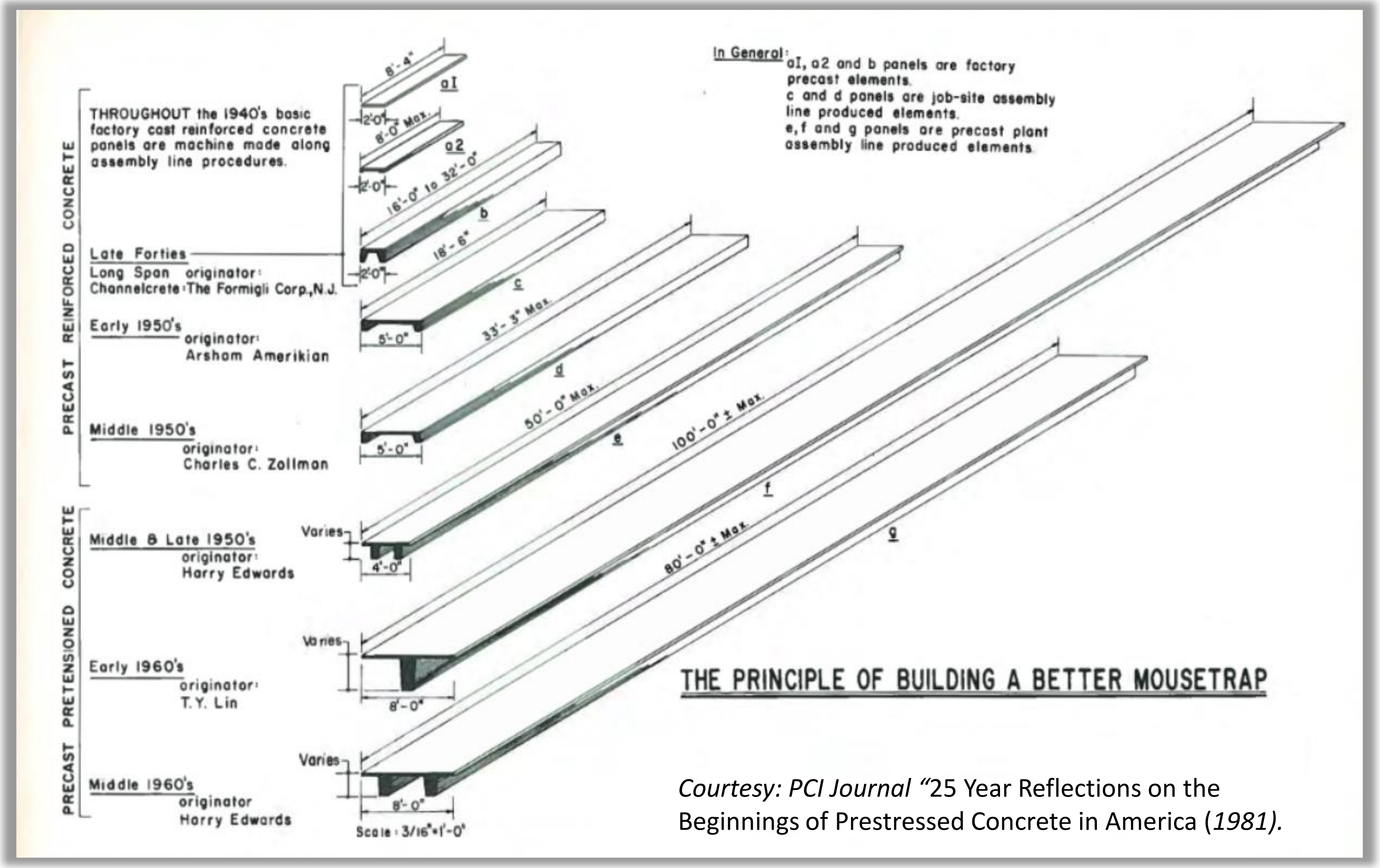
Florida Keys Bridges

Until 1978, all precast concrete segmental bridges were built by the balanced or progressive cantilever method, with the exception of smaller overpass structures. The first designs produced by Figg and Muller Engineers were for the Florida Keys bridge replacement program and included the Long Key Bridge, Seven-Mile Bridge, Channel Five Bridge, and Niles Channel Bridge

Courtesy: PCI Journal "Jean Muller: Bridge Engineer" (March-April 2006).

Prestressed Concrete Development in Florida

Evolution of the Double-Tee (1940 – 1960's)



Courtesy: PCI Journal "25 Year Reflections on the Beginnings of Prestressed Concrete in America (*1981*).

FDOT discontinued designing vehicular bridges using Double-Tees circa 1999 due to concrete cover, durability concerns, and unresolved longitudinal deck connection challenges

Prestressed Concrete Development in Florida

Evolution of the Bulb-Tee & Spliced Girders (1985 - 1993)

<u>**Eau Gallie Beam Tests**</u>

Service level test 6/11/1985

Ultimate load test 12/5/1985

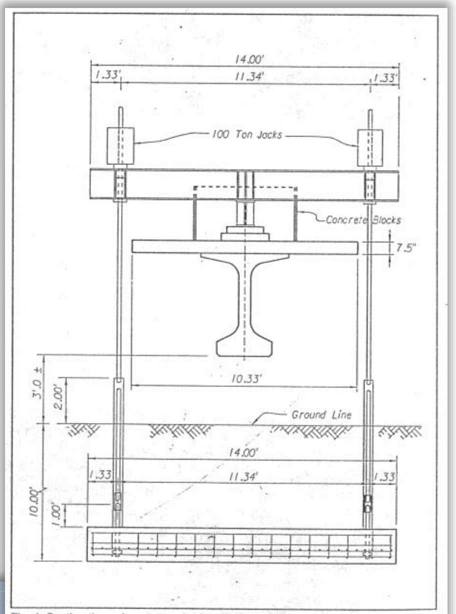
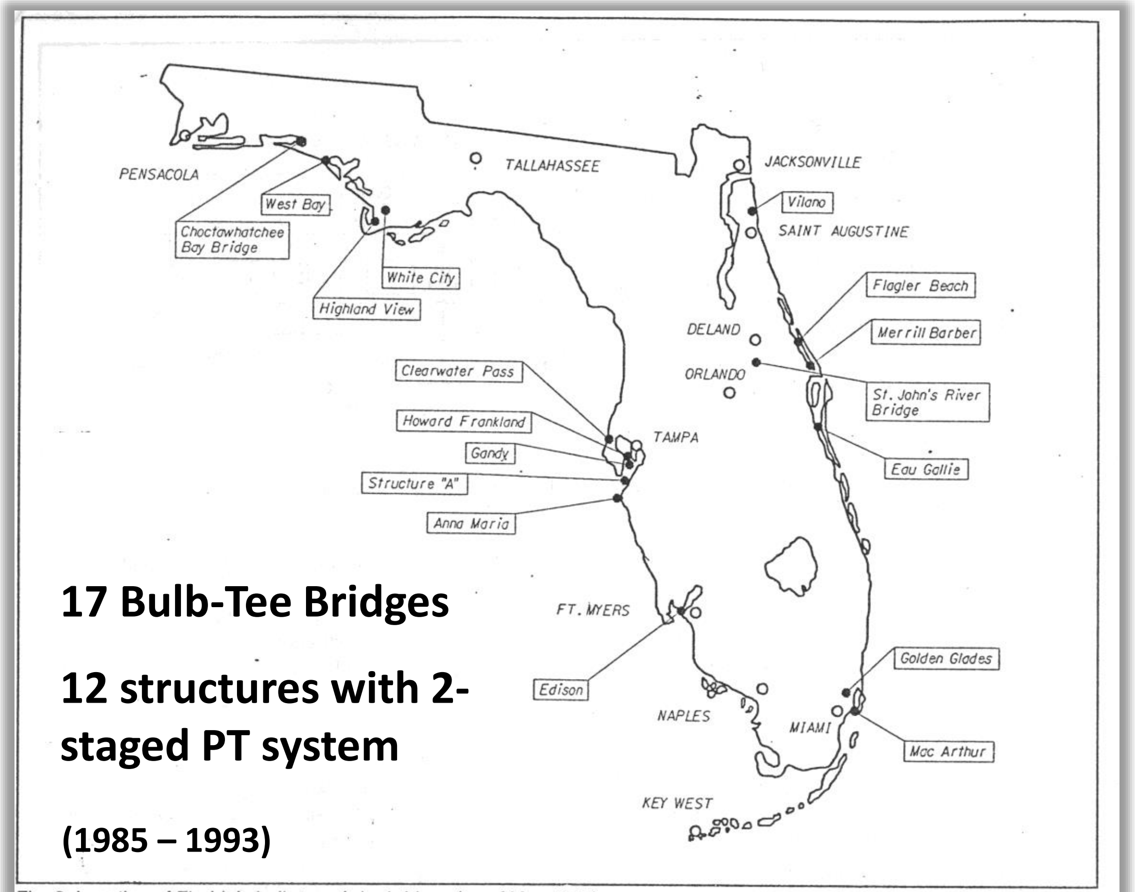


Fig. 4. Section through prototype bridge girder showing concentrated live load test assembly.



17 Bulb-Tee Bridges

12 structures with 2-staged PT system

(1985 – 1993)

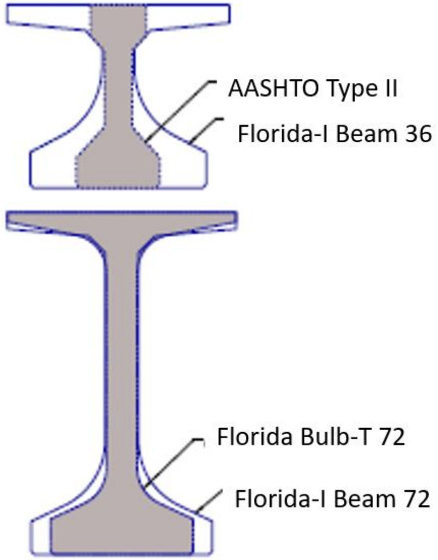
Fig. 2. Location of Florida's bulb-tee girder bridges (as of May 1993).

Link: History of Prestress in Florida

Prestressed Concrete Development in Florida

Evolution of the Florida-I Beam (2008 - present)

1st FIB-78 (2009)



Big John Monahan Bridge
FIB-84: 185-ft Span (2012)

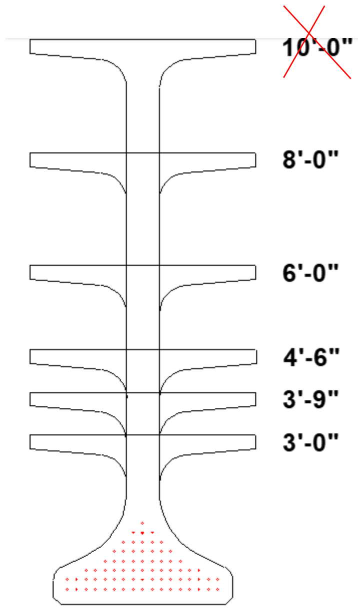
US 17-92 Interchange at SR 436 / Casselberry, FL.

FIB-96: 209-ft (2015)

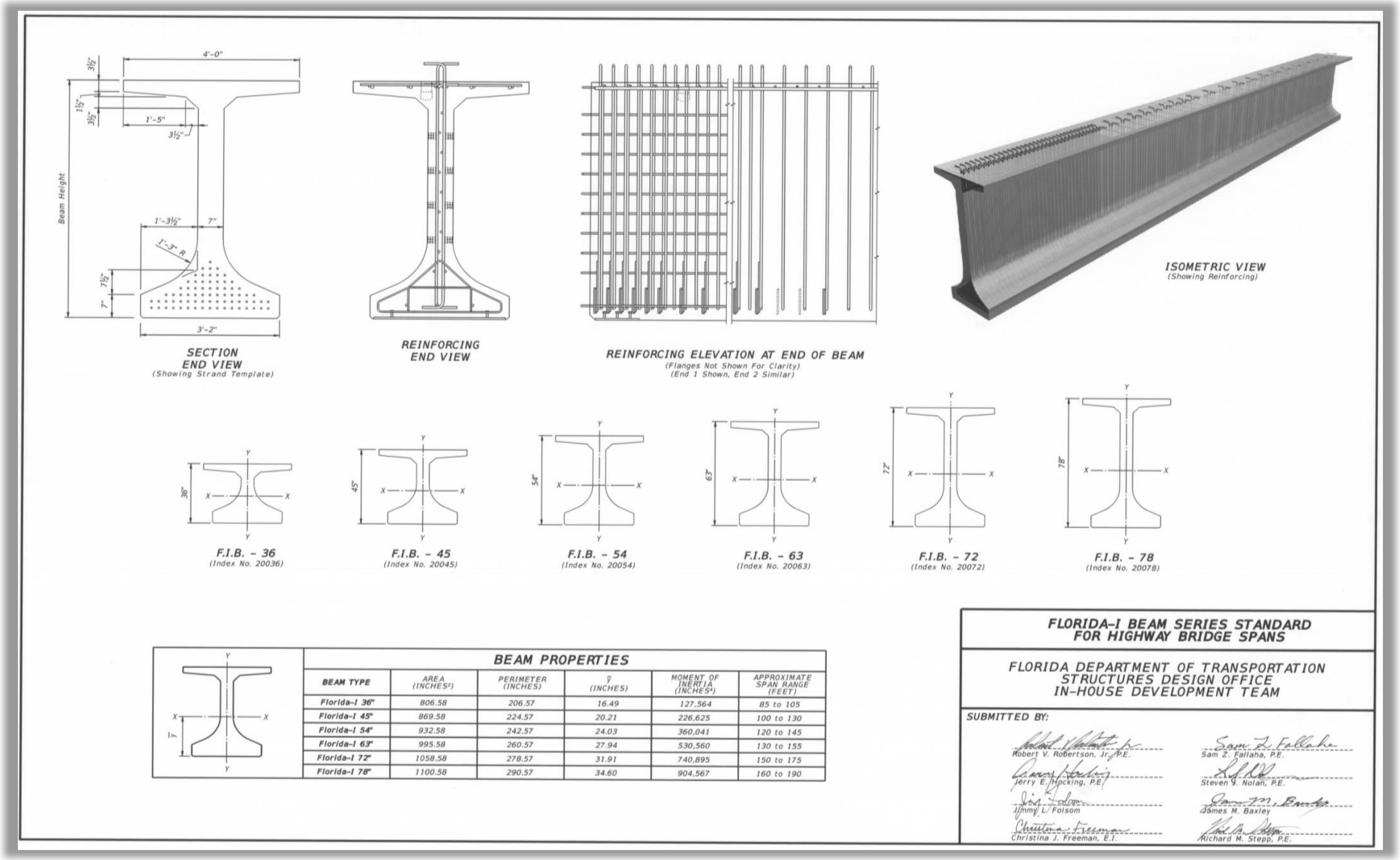
At 209 ft, the main-span beams are the longest single-piece precast, pretensioned concrete beams in the United States. Photo: The Lane Construction Corporation.

Prestressed Concrete Development in Florida

Evolution of the Florida-I Beam Standards (released 2009)



Conceptual Designs (late 2008)



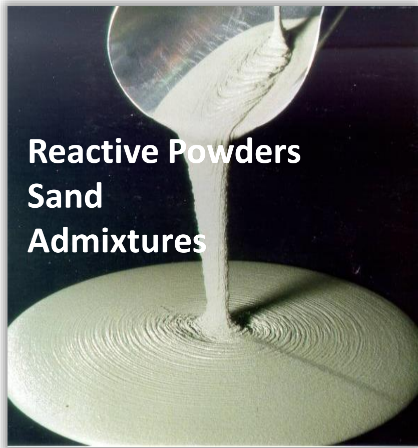
BEAM PROPERTIES

BEAM TYPE	AREA (INCHES²)	PERIMETER (INCHES)	$\bar{y}$ (INCHES)	MOMENT OF INERTIA (INCHES⁴)	APPROXIMATE SPAN RANGE (FEET)
Florida-I 36"	806.58	206.57	16.49	127,564	85 to 105
Florida-I 45"	869.58	224.57	20.21	226,625	100 to 130
Florida-I 54"	932.58	242.57	24.03	360,041	120 to 145
Florida-I 63"	995.58	260.57	27.94	530,560	130 to 155
Florida-I 72"	1058.58	278.57	31.91	740,895	150 to 175
Florida-I 78"	1100.58	290.57	34.60	904,567	160 to 190

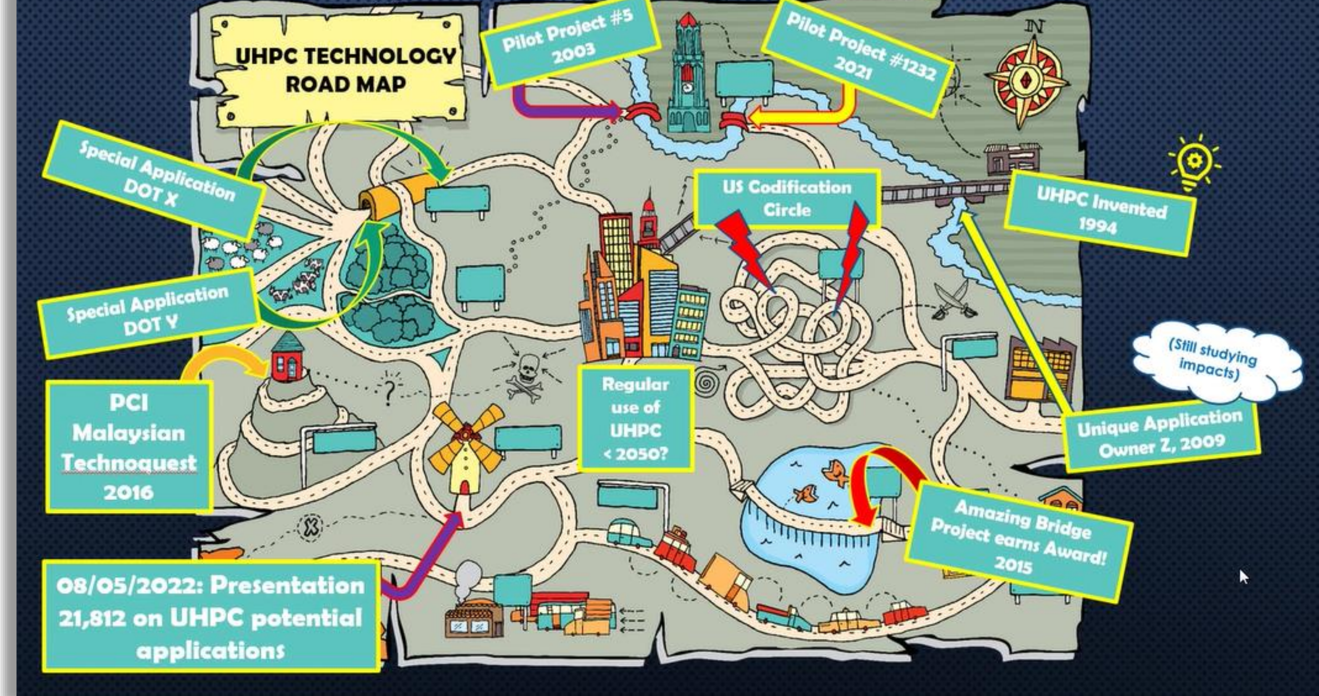
UHPC = Ultra-High Performance (fiber reinforced) Concrete

What is the attraction with UHPFRC:

- New & shinny (sort of 20’ish years old)
- Very strong in compression (~ 3x HPC)
- Modest tensile strength (~ 2x HPC)
- Post cracking ductility
- Almost impermeable to chlorides (uncracked)
- Really expensive



Courtesy of J.P. Binard (2023)



UHPC = Ultra-High Performance (fiber reinforced) Concrete

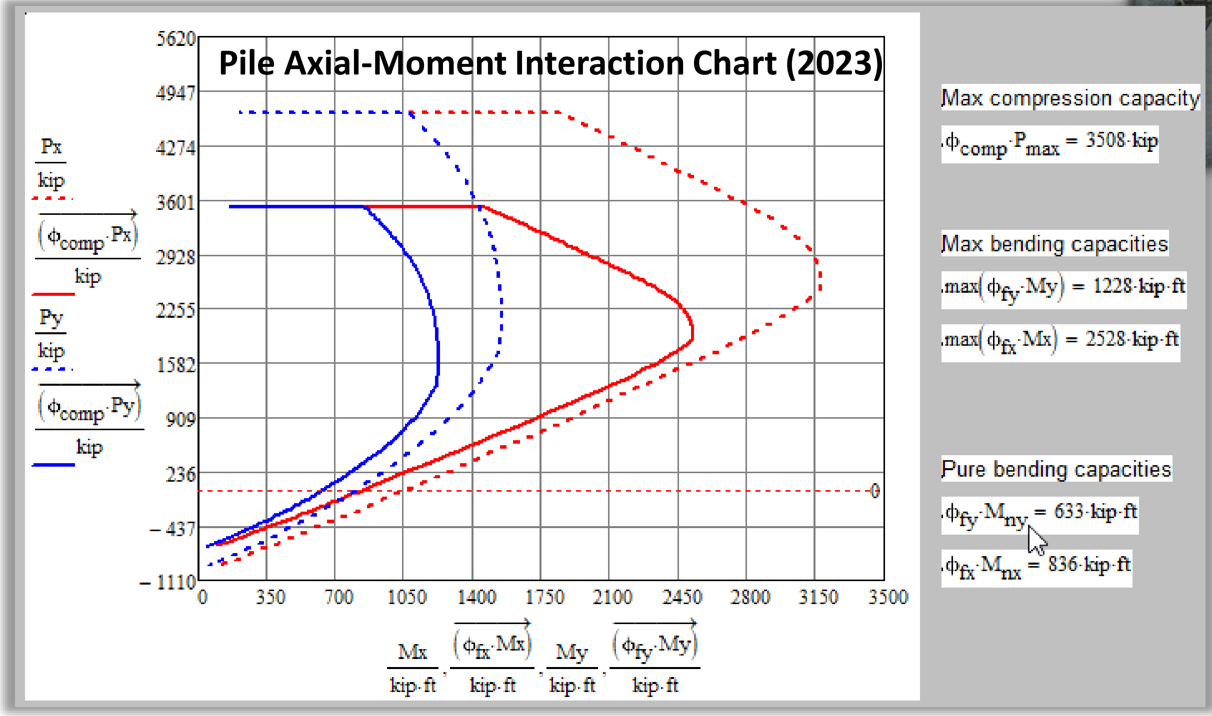
What has FDOT done with UHPC:

- New & shinny (sort of 20'ish years old)
- Very strong in compression (~ 3x HPC)
- Modest tensile strength (~ 2x HPC)
- Post cracking ductility
- Almost impermeable to chlorides (uncracked)
- Really expensive

Prestressed UHPC (Pull & Push Factors revisited)

Some apparent advantages of UHPC for RC & prestressed concrete for bridge members:

- Longer spans = fewer foundation units
- Thinner sections = less materials & handling costs
- Faster Fabrication
- Durability ?
- Aesthetics ?



Prestressed UHPC (Pull & Push Factors revisited)

So what have we investigated so far:

✓ Longer bridge spans = fewer foundation units

✓ Even thinner sections = less materials & handling costs

?? Faster Fabrication

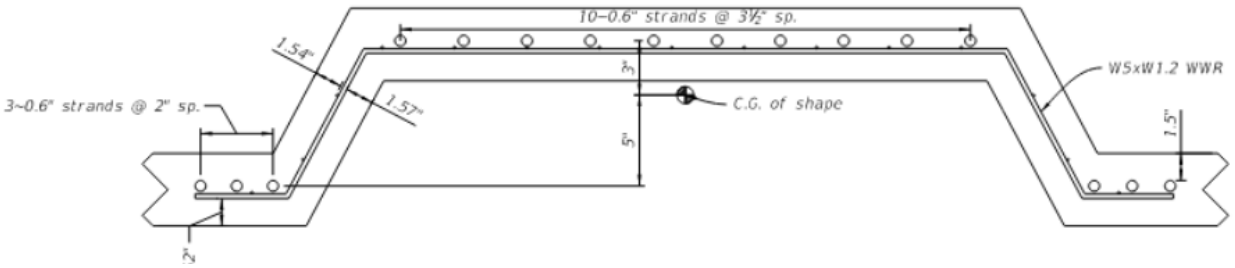
? Durability

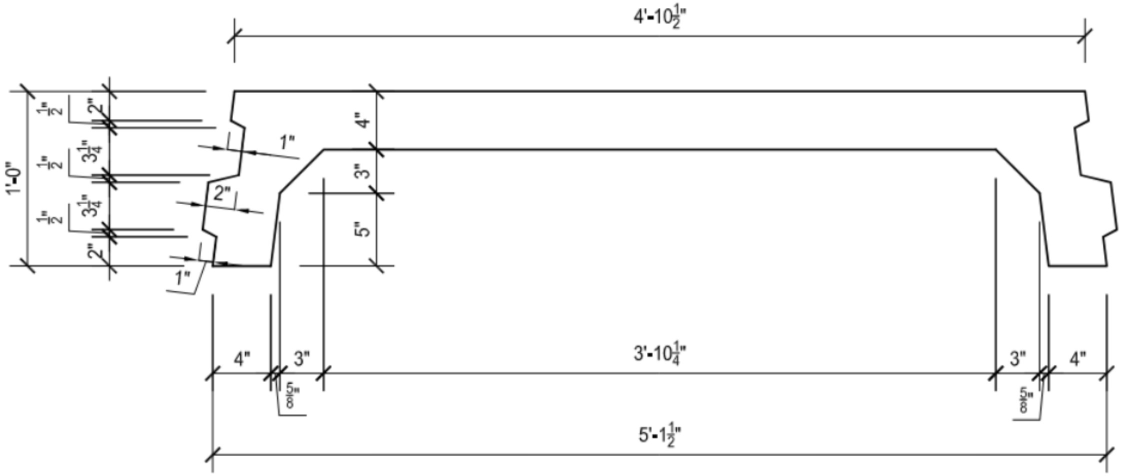
? Aesthetics

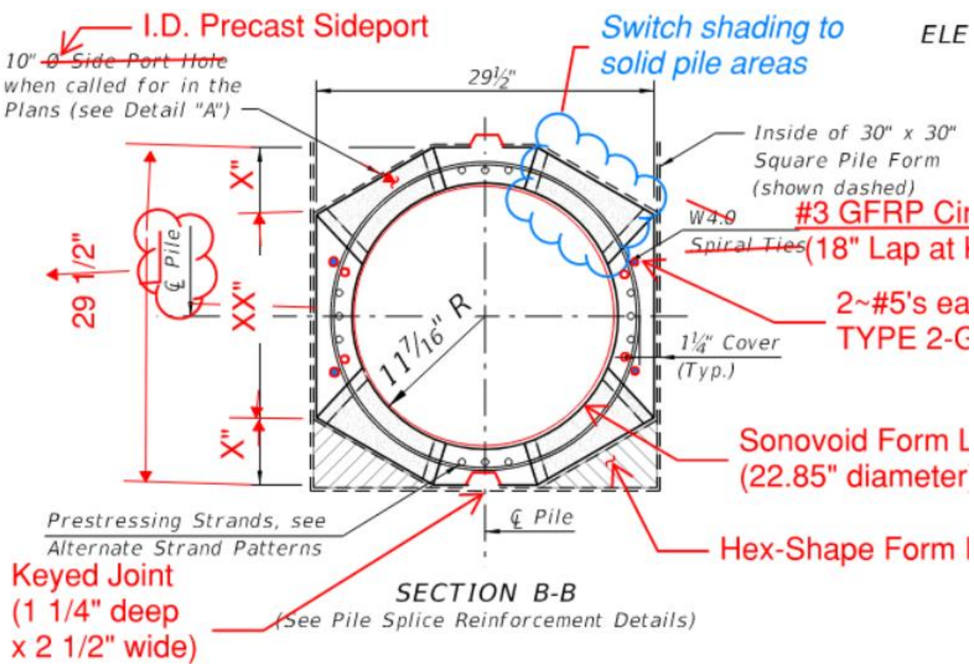
Prestressed UHPC (Pull & Push Factors revisited)

So what have we investigated so far:

✓ Sheet piles



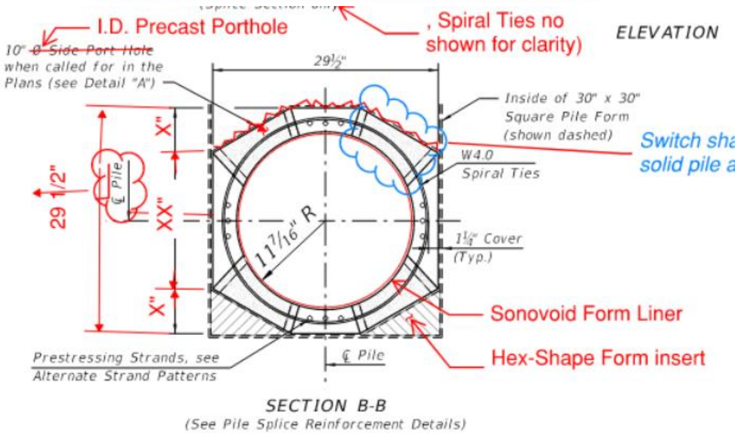


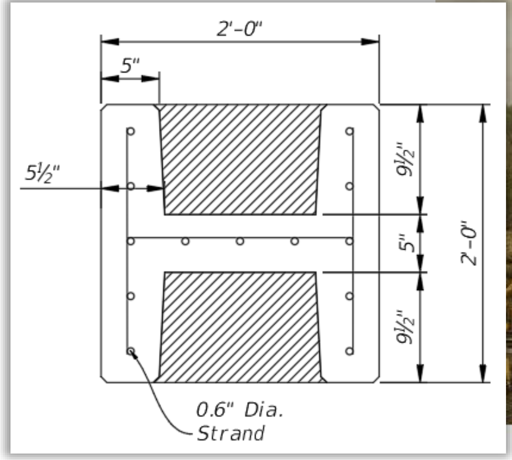


Prestressed UHPC (Pull & Push Factors revisited)

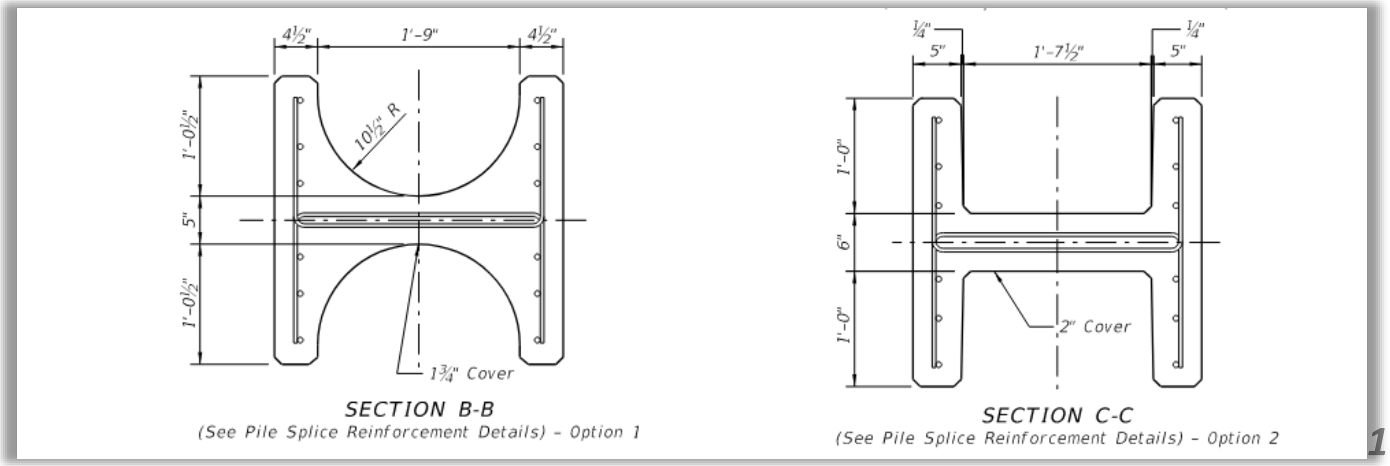
So what have we investigated so far:

- ✓ Bearing Piles





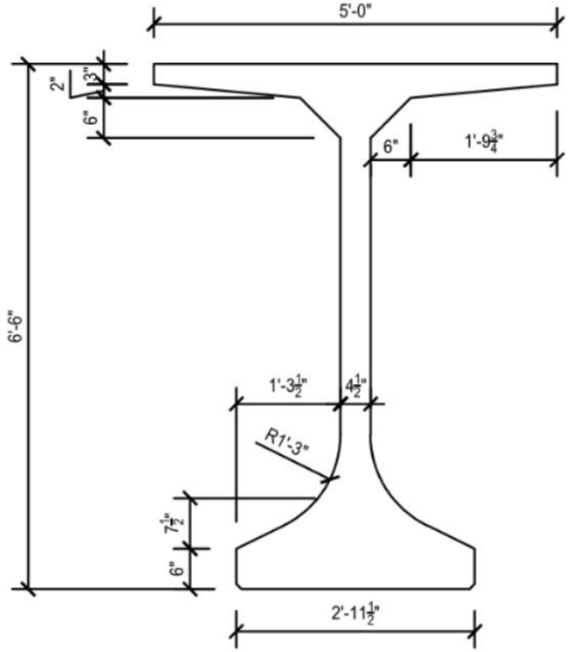
Pile driving photos coutesy of Cor-Tuf UHPC



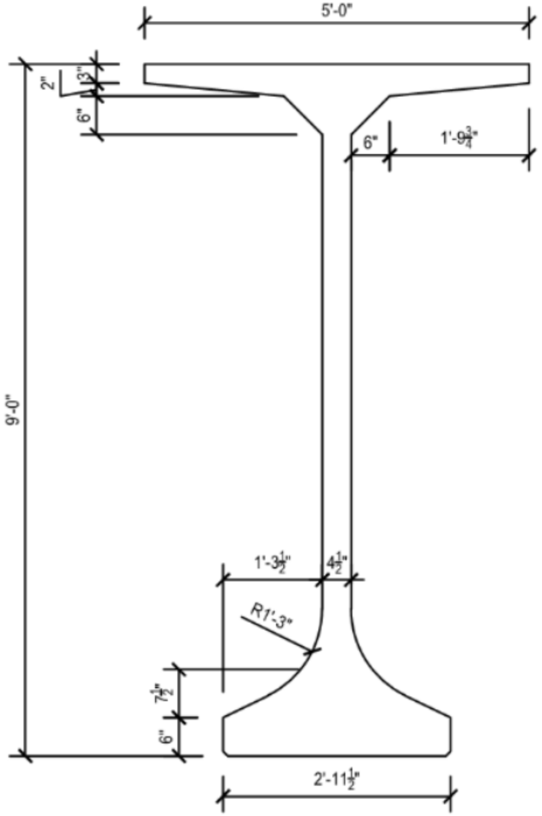
Prestressed UHPC (Pull & Push Factors revisited)

So what have we investigated so far:

- ✓ Bridge Girders

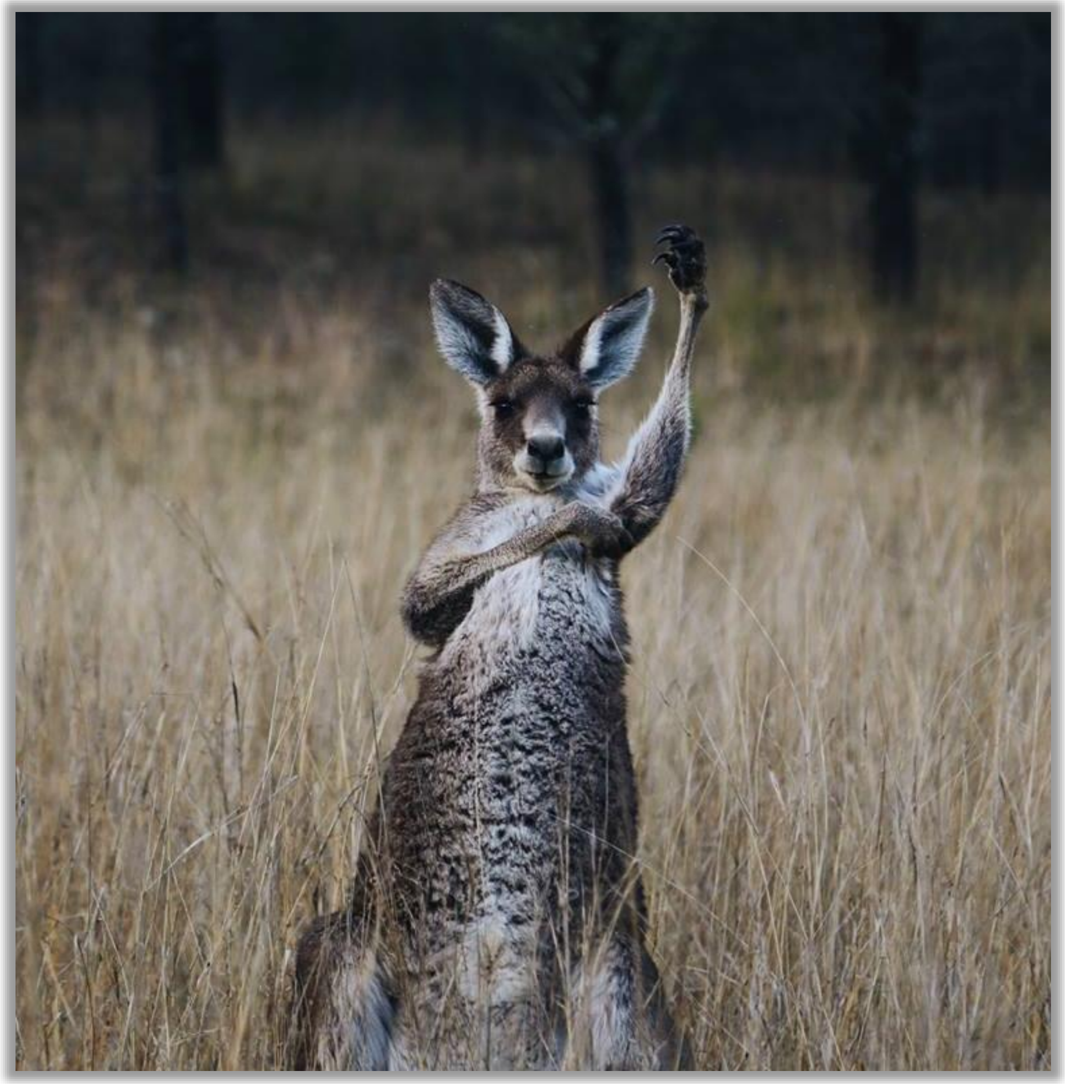


78 in. FIB – UHPC Beam



108 in. FIB – UHPC Beam

Questions?



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