Post-tensioned concrete structures are widely recognized for being extremely efficient and durable. But deficiencies in the U.S. educational system may be holding back even more widespread use of this versatile technology

The State of Post-Tensioned Concrete Education

Are universities in the United States missing opportunities to advance this important technology?

by Kenneth B. Bondy

Post-tensioned concrete is an important structural form in today's construction industry, with functional, economic, and sustainability benefits in all types of building structures. Because of that, there is a great need for practicing structural engineers to have expertise in prestressed concrete design. In reality, however, most structural engineers know very little about the design of prestressed concrete, and a major reason for that disturbing fact lies with our American university system. In this article, I will discuss the problem of prestressed concrete education at the university level, and I'll make some recommendations for improvements.

State of the Industry

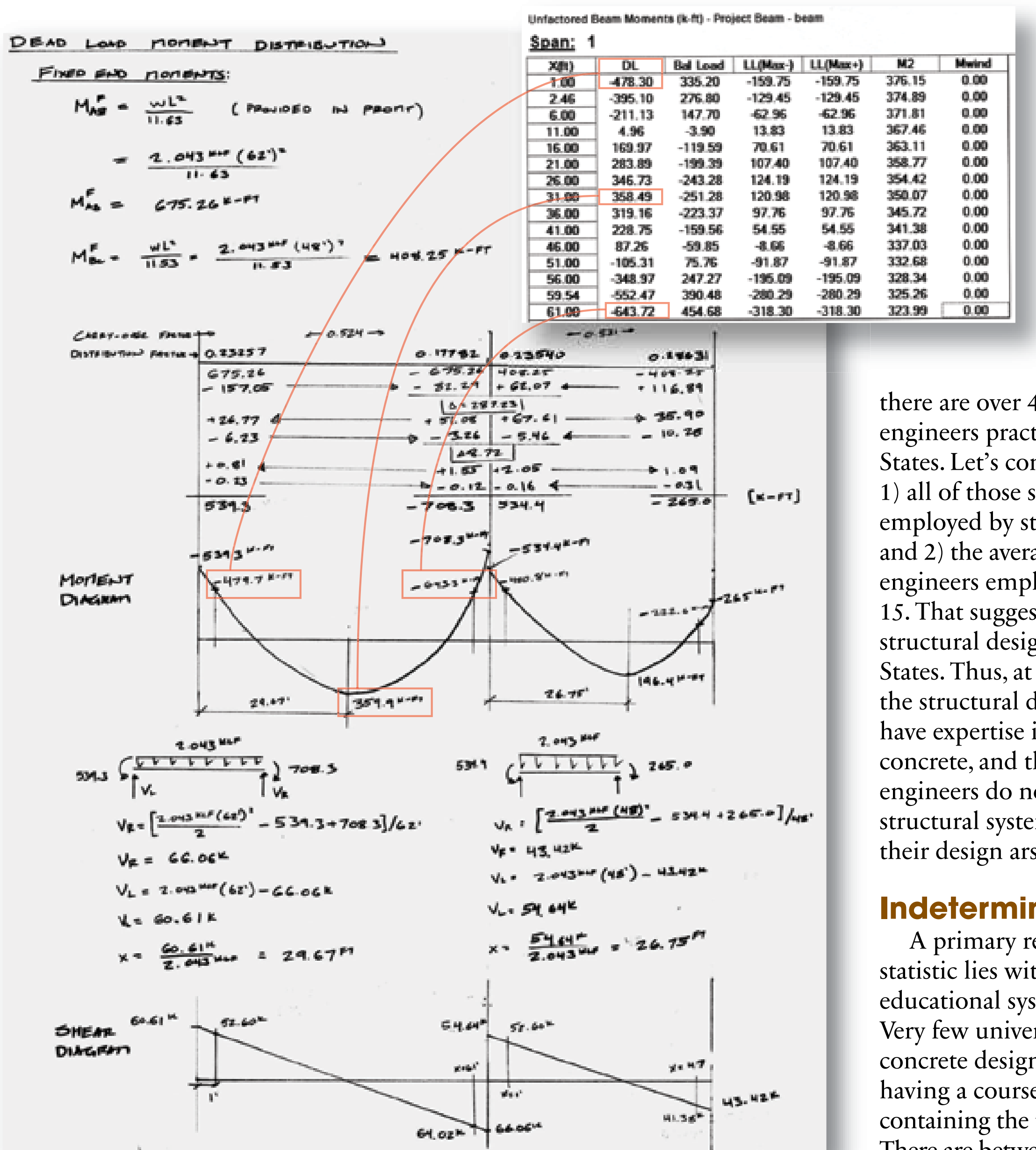
The first post-tensioned concrete buildings in the United States were built about 60 years ago in the mid-1950s. Based on tonnage statistics collected from member companies by the Post-Tensioning Institute (PTI), more than 50,000 post-tensioned concrete buildings have now been built in the United States, covering an estimated 5 billion ft^2 (more than 464 million m^2) of floor area.[1] Most of these buildings are still in service. It is unlikely that these numbers are overestimated because the member companies pay dues on their reported tonnage. These estimates are based on an assumed 0.8 lb of post-tensioning strand per ft^2 (3.9 kg per m^2) of floor area and an average building size of 100,000 ft^2 (9290 m^2).

That sounds like a lot of building construction. However, those of us in the post-tensioned concrete industry know that these numbers could be much greater. We constantly see examples of non-prestressed buildings in which the use of post-tensioned concrete would have resulted in significant economic and performance advantages. Why were these buildings constructed without post-tensioned concrete? A major reason is that expertise in the design of post-tensioned concrete is still, after 60 years, extremely limited. And one reason—perhaps the most significant reason—is the way that post-tensioned concrete design is being taught, or not being taught, at the university level.

Training…Then and Now

I started my career as a specialist in the design and construction of post-tensioned concrete buildings more than a half-century ago with the firm of T.Y. Lin and Associates. Three years later, I joined Atlas Prestressing Corp., a tendon manufacturing firm that also did design and installation work. At that time, the California, Texas, Illinois, and New York offices of T.Y. Lin were designing the vast majority of U.S. post-tensioned concrete buildings. Rather than simply waiting for those buildings to appear on the nation's bid alerts, Atlas recognized that the most effective way to increase the sale of post-tensioning was to teach other engineers how to design it.

We thus became heavily involved in education, including hundreds of full-day design seminars for practicing engineers, and extensive (free) in-house design assistance for structural firms. This technical approach, focused on teaching engineers how to design post-tensioning, was highly successful, and in a 10-year period, Atlas grew from the smallest to the largest American post-tensioning firm with offices across the United States and one in Europe (Amsterdam). As we watched the industry grow in the '60s and early '70s, we expected that, in a few decades, there would be hundreds of structural firms designing quality post-tensioned concrete buildings. Post-tensioning would become a commodity, an off-the-shelf item much like deformed reinforcing bar, and everybody would know how to design it.



Unfactored Beam Moments (k-ft) - Project Beam - beam

Span: 1

X(ft)	DL	Bal Load	LL(Max-)	LL(Max+)	M2	Mwind
1.00	-478.30	335.20	-159.75	-159.75	376.15	0.00
2.46	-395.10	276.80	-129.45	-129.45	374.89	0.00
6.00	-211.13	147.70	-62.96	-62.96	371.81	0.00
11.00	4.96	-3.90	13.83	13.83	367.46	0.00
16.00	169.97	-119.59	70.61	70.61	363.11	0.00
21.00	283.89	-199.39	107.40	107.40	358.77	0.00
26.00	346.73	-243.28	124.19	124.19	354.42	0.00
31.00	358.49	-251.28	120.98	120.98	350.07	0.00
36.00	319.16	-223.37	97.76	97.76	345.72	0.00
41.00	228.75	-159.56	54.55	54.55	341.38	0.00
46.00	87.26	-59.85	-8.66	-8.66	337.03	0.00
51.00	-105.31	75.76	-91.87	-91.87	332.68	0.00
56.00	-348.97	247.27	-195.09	-195.09	328.34	0.00
59.54	-552.47	390.48	-280.29	-280.29	325.26	0.00
61.00	-643.72	454.68	-318.30	-318.30	323.99	0.00

Homework assignments can combine classical (moment distribution) and computer-aided analyses to help students learn fundamental principles *(calculations courtesy of Ryan Nakamoto)*

That has not happened. Expertise in post-tensioned concrete design is still, even today, largely concentrated within the post-tensioning industry itself and in a small number of structural firms (who clearly benefit from the specialized knowledge). At a PTI conference less than 2 years ago, I found myself in a meeting room with executives from every major post-tensioning tendon supplier in the country. I asked each of them to estimate the total number of structural engineering firms in the country that could competently design a post-tensioned concrete building without help from the industry. The answers ranged from 20 to 30. The National Council of Structural Engineers Associations (NCSEA) reports that there are over 45,000 structural engineers practicing in the United States. Let's conservatively assume that: 1) all of those structural engineers are employed by structural design firms; and 2) the average number of structural engineers employed by a design firm is 15. That suggests there are about 3000 structural design firms in the United States. Thus, at most, about 1% of all the structural design firms in America have expertise in post-tensioned concrete, and the vast majority of U.S. engineers do not have this powerful structural system available to them in their design arsenals.

Indeterminate Subjects

A primary reason for this shocking statistic lies with the engineering educational system in this country. Very few universities teach prestressed concrete design, with even fewer having a course specifically on or containing the topic of post-tensioning. There are between 2500 and 3000 public and private 4-year universities in the United States.[2] Of those, 224 have colleges of civil engineering.[3] Based on personal communication with many friends in academia and on the PTI staff, as well as other sources of information about civil engineering education, I estimate that a maximum of 30, perhaps as few as 20, of those 224 colleges of engineering teach a course in prestressed concrete.

So of all the civil engineering programs in this country, only about 10% of them teach a course in prestressed concrete. College is where students should be getting their first valid taste of post-tensioning design, but they clearly are not. As a result, graduating structural engineers are not sufficiently trained and must learn on the job if they are to use post-tensioning in their future designs. This is akin to a tradesworker such as a carpenter going through apprenticeship school and not learning how to use a hammer or saw. These facts do not bode well for the growth of the post-tensioning industry.

Another problem is that those universities that do teach prestressed concrete often do not adequately address key fundamentals of post-tensioned concrete. Professors who actually think they ARE teaching post-tensioned concrete in their classes are often not teaching it correctly. Vast amounts of time are spent dwelling on relatively unimportant subjects such as prestress losses and concordant tendons, which from a design standpoint could be adequately covered in 15 minutes, yet critically important things such as secondary effects (reactions, moments, and shears) are completely ignored.

Field trips are great ways to tie lectures to real-world applications, and including a little fun can ensure it's a lasting memory. After a field trip to an externally post-tensioned retrofit project, Dirk took the entire class out to lunch at Joe's Crab Shack in Newport Beach, CA. Here they are at Joe's—hard at work learning a dance step (and no doubt thinking about moment distribution)

Each summer for 6 years (2002 to 2007), I've presented the lecture "Teaching Post-Tensioned Concrete Design" at an annual seminar for civil engineering educators called "The Engineering and Economics of Reinforced Concrete Buildings." The seminars were sponsored by the Portland Cement Association (PCA) and were conducted at their headquarters in Skokie, IL. This is a highly popular and successful event, in which PCA invites about 30 civil engineering professors each year to attend a 4-day series of seminars addressing all aspects of reinforced concrete design. My talk was always on the last day of the seminar, and I would usually arrive in Skokie the day before, when in the evening PCA hosted the group to a nice farewell dinner at a local restaurant. I would attend the dinner and get to know the professors. Most of the professors I talked with felt that they had a good background in post-tensioning and were teaching all of the important design considerations to their students. A common remark I heard was, "Hey, I'll be at your talk tomorrow, but I teach prestressed concrete and I already know all that stuff…" Then tomorrow came.

The very first thing I said in my talk was that because most post-tensioned concrete members are indeterminate, it was impossible to competently teach post-tensioned concrete design with a determinate "simple-span" beam model. The unique and critically important effects of secondary reactions, moments, and shears could not be taught with a determinate model because they do not exist in a determinate model. Secondary effects in post-tensioned concrete members can only be taught using an indeterminate model.

You could almost hear the jaws dropping to the tables. I went on to explain that secondary effects was not the only thing that couldn't be explained with a determinate model. The critical relationship between balanced tendon loads in adjacent spans—a design issue that has caused many field problems—cannot be explained unless there ARE adjacent spans, as in a multi-span indeterminate model. After this, the professors did seem to pay rapt attention to the rest of my talk—many notes were taken.

A Clear and Present Demand

The lack of interest in prestressed concrete education certainly does not extend to the student level. While most of my career was as a practitioner, I do have some academic experience, and it forms the basis for many of the opinions I am expressing herein. I taught a senior undergraduate class in prestressed concrete design for 16 years at the University of California, Los Angeles (UCLA) in the '80s and '90s. Enrollment was 15 students in the first year, quickly growing to over 40 for each of the last 10 years.

Since 2011, my son Dirk has taught the same class. He is an experienced structural engineer and, like his dad, is a specialist in the design of post-tensioned concrete structures. As I was, he is making a living doing the very thing he is teaching. In 2011, the first year Dirk taught the UCLA class, enrollment was 19 students and the class was scheduled to be taught only every other year—if there was any demand. In 2012, enrollment jumped to 35, then 43, and in 2014, it reached a high of 54 students. Graduate students who have reached their undergraduate course limit have complained about not being able to take the class, so next year, it is likely to be a dual undergraduate/graduate course, probably with even larger enrollment. This is what happens when prestressed concrete is taught correctly. Clearly, there is a great demand at the student level for a prestressed concrete class that properly addresses post-tensioned concrete.

Dirk's current course includes a term project in which students match their manual calculations with computer calculations done by a student version of PTData, a commercially available computer program for the design of post-tensioned structures. The program, furnished free of charge, is limited to just two spans but is otherwise fully functional. This student version of PTData is also available at no charge to any professor or enrolled student who asks for it. The students love doing this project; it is a great learning tool and gives them confidence in their work. Many have taken their completed project to job interviews. Structural design firms have reported back to Dirk that they are extremely impressed with what the students are learning at UCLA and, when they hire a UCLA graduate who has taken his class, how much they appreciate the unexpected injection of specialized post-tensioning design knowledge into their office.

UCLA now requires each 4-unit civil engineering design class to include a 2-hour discussion period each week, along with the 4 hours of instruction. The discussion period is normally led by a teaching assistant (TA). In 2013, Dirk asked me if I would be his TA. I accepted and have now completed 2 years as the oldest (and lowest paid) teaching assistant in the history of the University of California. At the discussion periods, I solve all the homework and midterm assignments for the students and answer many relevant questions about careers in prestressed concrete. UCLA decided to record video of our class this spring (including my discussion sessions along with Dirk's lectures) and make all the videos available to anyone at no charge. Thus, the entire 10-week class can be audited by anyone in the world, from anyplace in the world, at any convenient time. Upon request, we will furnish anyone with the homework assignments and the exams (the solutions can be viewed in my discussion sessions). With this extraordinary tool, any student at any university in the world can audit our class, and civil engineering professors can observe how we think post-tensioned concrete should be taught at the university level. The link to the videos is: **www2.oid.ucla.edu/webcasts/courses/2013-2014/2014spring/cee143-1**.

Stressing Education

Finally, what can be done to help stimulate, encourage, and improve the teaching of post-tensioned concrete at the university level? Increased participation in education on the part of PTI is perhaps the best option. That might include funding professorships, research, and doing more design seminars for practicing engineers. There is also a possibility that PTI will sponsor a "Professor's Seminar," focused, of course, on post-tensioned concrete, to supplement the ones PCA offers. We also hope that the availability of our UCLA class videos will encourage the development of similar prestressed concrete design classes in universities where the subject is not presently taught, and will improve the quality of instruction at schools where it is.

Acknowledgments

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Selected for reader interest by the editors.

Kenneth B. Bondy, ACI Honorary Member, has been involved in the design and construction of concrete building structures for 51 years, specializing in post-tensioned concrete and the strengthening of existing buildings using externally applied post-tensioned tendons. A civil engineering graduate of the University of California at Los Angeles (BS '63, MS '64), he is a licensed civil and structural engineer in California and has been licensed in several other states. He is a member of ACI Committees 132, Responsibility in Concrete Construction; 318, Structural Concrete Building Code; and 332, Residential Concrete Work; and Joint ACI-ASCE Committee 423, Prestressed Concrete. Bondy is a member of the "Legends of Post-Tensioning" Hall of Fame of the Post-Tensioning Institute, where he is also an Honorary Lifetime Member and Fellow.