



WATERPROOFING WITHOUT MEMBRANE

Forty years after completion, a post-tensioned shrinkage-compensating concrete mat foundation is still solid and watertight



Fig. 1—500 First Street, NW is an eight-story building with two basement levels. Like many sites in the Washington, DC, area, there were significant groundwater issues to contend with in constructing the foundation. Erected in 1967, it was the first building in the city constructed with post-tensioning. (Photo by Steven H. Miller, courtesy of CTS Cement Manufacturing).



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One of the most reliable measures of success in construction is the test of time. The common wisdom that a construction method takes 40 years to mature is partly based on the need to see how well the technology, and the structures built with it, endures. An office building in Washington, DC, built using a then-innovative post-tensioned mat foundation cast with shrinkage-compensating concrete, bears witness to the effectiveness and durability of its engineering and materials. Built below the water table without a waterproofing membrane, it has remained crack-free and watertight for over 40 years.

SITE CONDITIONS

Washington, DC, is built on water. Local historians dismiss as myth, the notion that it was built on a swamp, but there is indisputably a high water table. The central city perches between two converging rivers, and there are buried creek beds in many places.

There are an abundance of water-proofing

contractors in the area, because any basement excavation deeper than 8 ft (2.4 m) below ground level needs a water-proofing system. The most common construction technique combines a waterproofing membrane with a drainage system surrounding the concrete consisting of a 12 in. (300 mm) layer of gravel that is drained by the ongoing operation of a sump-pump.

The office building at 500 First Street, NW was the first post-tensioned building constructed in Washington, DC. It was designed by Weihe Black & Kerr Architects, Washington, DC. Structural engineering was done by Keith Thornton, then Vice President of T.Y. Lin and Associates and Manager of the firm's New York office. The Lin firm pioneered post-tensioned structural concrete in the U.S. Design documents date from February 1966, and the building was completed in April 1967 (Fig. 1).

Below-ground water was a critical issue for 500 First Street. The site lies less than 1.5 mi (2.4 km) from the Potomac River and approximately 1.75 mi (2.8 km) from the Anacostia River, both of which flow directly into the Chesapeake Bay. Street elevation at the site is approximately 20 ft (6.1 m) above sea level, and the excavation quickly struck groundwater. The water level rose noticeably whenever the tide came in. During construction, there were two pumping systems on site: one in constant use and a second that was activated during high tide.

The building was originally planned with three basements. After excavating 22 ft (6.7 m) for two basements, they had pumped



so much water out of the pit that plans for the third basement were abandoned. There was a hydrostatic head of 17 ft (5.2 m), and the mass of the building would not overcome its buoyancy until construction reached the sixth floor. There was some question whether the weight of the eight-story structure would have been sufficient to hold the foundation down if it had been excavated another 10 ft (3 m).

ENGINEERING STRATEGY

Given the soil conditions, engineers concluded that a post-tensioned mat foundation would be the most economical solution. A mat foundation—sometimes referred to as a raft foundation—is essentially a thick slab that spreads the load of the superstructure over the entire footprint of the building rather than concentrating it at discreet points. The building, in essence, “floats” on the soil.

Because post-tensioning greatly increases the strength of a concrete slab of a given thickness, the post-tensioned mat foundation could be made sufficiently strong at a reduced thickness as compared to a conventionally reinforced slab. Conventional steel bar reinforcement is passive; that is, it only begins to provide tensile strength after the concrete’s own tensile strength has been exceeded by the load and the concrete has begun to crack. Post-tensioning steel is active: by putting the concrete in compression, it increases the slab’s ability to resist tensile load before cracking. In addition, the Lin firm had found that increased load balancing could be achieved by draping the tendons in a curved shape through the thickness of the slab, so that stress applied to them would not only create horizontal tension but also provide a vertical thrust to resist load. Thus, the steel was doing double duty, both strengthening the concrete and resisting some of the dead load. The result was that much less concrete thickness was needed to support a given structure.

Constructing the building with post-tensioning

reduced the thickness of the foundation slab by 33%. The price of post-tensioning was lower than the additional concrete thickness and associated reinforcement would have been, even in 1966.

(Subsequent increases in the availability of post-tensioning and improvements in the technology have made it relatively even more affordable.)

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In addition to more efficient load bearing, the post-tensioned slab provides an effective means of waterproofing.

post-tensioned slab provides an effective means of waterproofing. Post-tensioned slabs do not have control joints. The stressed tendons put the slab into compression, which tends to prevent shrinkage cracking.

Shrinkage-compensating concrete made with Type K cement was also employed as an adjunct crack-prevention technology. Shrinkage-compensating concrete virtually eliminates drying-shrinkage cracking because the concrete expands during its first 7 days after placement. It is kept wet constantly during this curing period. When it is allowed to dry, it undergoes normal

shrinkage; but that reduction in dimension is offset by the previous expansion, producing a net shrinkage close to zero.

The interaction of post-tensioning and shrinkage-compensating concrete works in two significant ways to waterproof a foundation. In the long-term, both technologies contribute to elimination of cracking. When the slab is first placed, however, only the shrinkage-compensating concrete is preventing cracking. Post-tensioning stress cannot be applied until the slab has attained a specified level of compressive strength, generally approximately 75% of the mixture design strength. In the 500 First Street foundation, it was specified at 3000 psi (21 MPa), a strength which takes several days to achieve. Drying-shrinkage cracking in conventional concrete usually occurs during those same first few days. Shrinkage-compensating concrete is still expanding during this time, making it virtually immune to drying shrinkage. The shrinkage-compensating concrete prevents cracking in those critical few days, buying time for the slab until prestress can be applied.¹

DESIGN

The 500 First Street foundation is 24 in. (609.6 mm) thick, with drop panels an additional 24 in. (610 mm) thick (that is, 48 in. [1220 mm] total thickness) at the bases of the structure’s main support

columns. This configuration of drop panels was repeated in the upper floor decks, though with greatly reduced thicknesses. While drop panels had been used before this in conventionally reinforced concrete construction, this was the first time the concept was employed in a post-tensioned design.

The foundation slab is post-tensioned in both north-south and east-west dimensions. Post-tensioning tendons run under the centers of the columns and also flank the columns on

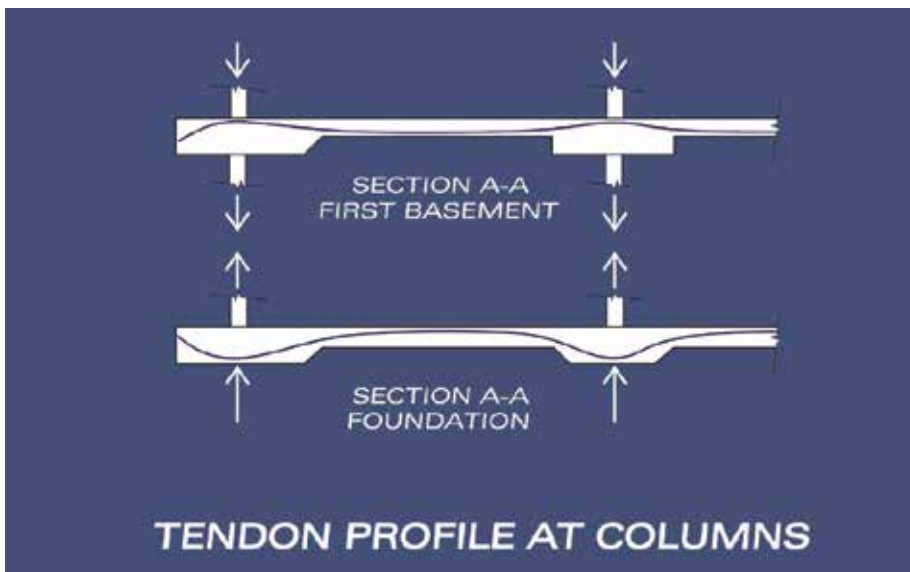


Fig. 2—In the foundation, post-tensioning tendons loop down under the building's load-bearing columns. When stressed, the horizontal tension creates vertical thrust where the tendon dips down. This thrust helps resist the vertical load of the building. In the floor slabs, however, the post-tensioning tendons are at their highest points over load-bearing columns and drape down across the floor spans. When stressed, they provide upward thrust that resists the dead load of the floor, preventing the floor from sagging across the spans. Building's floor decks are a mere 6 in. (150 mm) thick and span 32 ft (9.8 m). (Illustration courtesy of CTS Cement.)



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both sides at distances ranging from 5.5 to 8 ft (1.7 to 2.4 m) from the column centers. Tendons were seven-strand, 0.5 in. (12.7 mm) steel, greased and paper-wrapped. The specification called for either paper-wrapped or plastic-sheathed tendons, the former being the older technology. In the years immediately following this project, paper-wrapped tendons disappeared from the industry in favor of the plastic-sheathed variety. The paper wrapping was easily damaged; and indeed, on this project, some of it was compromised by water exposure during shipment and had to be rejected at the job site. Nonetheless, the paper-wrapped tendons that were used functioned properly, as the durability of the building proves.

To waterproof below-grade walls, there

are draped post-tensioning tendons; and shrinkage-compensating concrete was specified.

In the foundation, the tendons loop up and down across the length and breadth of the slab. They dip down under into the drop panels and are at their lowest point—just 3 in. (75 mm) from the bottom of the slab—directly underneath the columns. They are at their highest point halfway between the columns. When stressed, the diagonal path of the tendon provides a strong upward thrust component under the columns, helping to balance the load of the superstructure.

Post-tensioning was also used in all floor decks of the building, but there, tendon-placement followed an opposite

strategy. Tendons are near the top of the slab thickness just over the columns. They dip down across the span between columns, providing maximum uplift at the center of the span to resist the dead load of the floor (Fig. 2).

This additional strength allowed the floor-slab thickness to be reduced to 6 in. (150 mm). The drop panels surrounding the columns add an additional 10 in. (250 mm), for a total deck thickness of only 16 in.

(410 mm). Ductwork snakes around the dropped panels, making maximum use of the space. This saved enough floor-to-floor height to get an entire extra story into the building and still stay within the Washington, DC, building code's absolute height limit.

Shrinkage-compensating concrete was still a new material; the first structure had been built with it less than 5 years before. The material has proved extremely durable. The Chem-Comp expansive cement used to make it has continued to evolve, and it is available today in an improved form.

CONSTRUCTION

One problem that occurred during construction resulted from the amount of uplift force provided by the post-tensioning tendons in the foundation. The slab was cast in two stages. Due to practical matters of access to the jacking-points, the slab tendons had to be tensioned before the basement walls were placed and, therefore, before there were any columns or superstructure load on the slab.

The first half of the slab was placed, and 3 days later, the tendons were stressed. Uplift from stressing, unopposed by any load, was so forceful that one of the drop panels popped out of the slab.

A solution was suggested by Ed Rice, Co-Founder and President of T.Y. Lin and Associates, and also one of the developers of the Chem-Comp shrinkage-compensating



cement used on the job. The slab had cracked along a path following the drape-arc of the tendons. Vertical holes were drilled into the damaged sections, traversing the two separated pieces of concrete. A bearing-plate and vertical post-tensioning bars were inserted and grouted into place. Once the grouting had cured, stress was applied, effectively suturing the slab together.

In the remaining half of the foundation, tendon placement was modified. The low point of the tendons was raised by 12 in. (300 mm). In addition, steel reinforcing bars were placed in the slab around the dropped panels, not to bear the load of the super-structure but to counteract the unloaded uplift of prestressing until the building's load could be applied.

PROOF OF CONCEPT

Forty years later, 500 First Street is stable, occupied and functioning well. The second

basement—the floor of which is the foundation slab—is crack free and does not leak (Fig. 3). The below-grade walls also remain watertight (Fig. 4). The only sign of water damage in the basement is from a roof leak in the elevator shaft.

One common source of leakage below grade can occur around the diagonal braces—called rakers—that protrude through the cast concrete walls. Rakers are used as temporary support for the lagging that is placed around the excavation before the foundation is cast. When the concrete walls are placed, the rakers are still in position; they are cut off inside after the walls have cured. They can create stress points that compromise the concrete and cause leaks. There is no evidence, however, of any such leakage at 500 First Street, possibly due to the effective combination of shrinkage-compensating concrete and post-tensioning (Fig. 5).

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Original publication: Thornton, K., Chusid, M., & Miller, S. H. (2009, August). Waterproofing Without Membrane. PTI Journal, 43-46.



Fig. 3—The floor of the second basement is actually the top surface of the foundation. Forty years after construction, it is crack-free, watertight, and completely dry. The 10 in. (250 mm) thick drop panels of the first basement deck are clearly visible in the ceiling of this photo: they resemble broad soffits surrounding the load-bearing pillars. (Photo by Steven H. Miller, courtesy of CTS Cement Manufacturing.)



Fig. 4—Even at the meeting point of foundation and basement wall, there is no evidence of cracking or leakage. (Photo by Steven H. Miller, courtesy of CTS Cement Manufacturing.)



Fig. 5—Forty years later, the building is stable and in excellent condition. The thin deck-slabs made possible by posttensioning allowed the designers to get an extra story into the structure and still stay under the city's absolute height limit. The building is currently occupied by offices of the Federal Bureau of Prisons. (Photo by Steven H. Miller, courtesy of CTS Cement Manufacturing.)