LIGHTWEIGHT CONCRETE PRECAST DOUBLE TEES SPEED CONSTRUCTION IN THE 48-STORY DUKE ENERGY CENTER

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ABSTRACT
Precast, prestressed concrete double tees are often used for the construction of industrial building walls and roofs and for multi-story parking structures. It is very unusual, however, to use double tees in a high rise office building. This case study will discuss the use of lightweight concrete double tees to speed up construction of the 1.4 million-sq-ft, 48-story Duke Energy Center in Charlotte, NC. The benefits of lightweight concrete for building construction are also reviewed.

Keywords: Lightweight concrete, Duke Energy Center, Precast Prestressed Concrete Double Tee, Lightweight Aggregate, Fire Resistance, Transportation, Internal Curing

INTRODUCTION

The new 48-story Duke Energy Center tower at 764 ft (233 m) is the second tallest building in Charlotte, NC and the tallest in the world to use precast, prestressed double tees[1]. The building was originally known as the Wachovia First Street Office Tower, but was renamed after Wachovia was purchased by Wells Fargo at the end of 2008. The name change was in recognition of Duke Energy's presence in the building[2]. Duke Energy will move its corporate headquarters to the new 1.4 million-sq-ft office building as early as mid-to-late 2010 and will occupy approximately 500,000 sq ft.

Figure 1 Model of Duke Energy Center and
First Street Cultural Campus Development

The office tower is one of several buildings in a project that was originally developed as the Wachovia Cultural Campus, now simply known as the First Street Cultural Campus. The original plan included a 42-story condominium tower, the Mint Museum of Art, the Bechtler Modern Art Museum, the Harvey B. Gantt Center for African-American Arts and the Knight Theater. The museums and theater are currently under construction; however, the future of the condominium, which was designed to be built above the five-story Mint Museum structure, is uncertain due to the economic crisis and construction has now been postponed. Figure 1 shows the Duke Energy Center tower on the left and the postponed condo tower on the right.

OFFICE TOWER DESIGN

Atlanta-based architectural firm tvsdesign designed the office tower with a nine-story annex "podium" that contains four floors of trading space for Wachovia/Wells Fargo, and an underground parking deck. The four floors of trading space have floor-to-ceiling heights of 20 ft. The eight-level below-grade parking garage for 2,200 cars reaches a depth of 95 ft below the street level with a loading dock on the lowest level. Trucks access the loading dock through a tunnel under the Harvey B. Gantt Center with a service entrance a block away. Cars access the parking garage through a second tunnel that sits above the service entrance tunnel. Because the project is located within Charlotte's Uptown Mixed-Use District, the designers had to adhere to guidelines for service vehicles not backing onto the street. "A huge part of the project was to make the cultural campus pedestrian," says Dave Brown, associate principal with tvsdesign. "We had to design as if it had no backyard. Everything was a front door[2]."

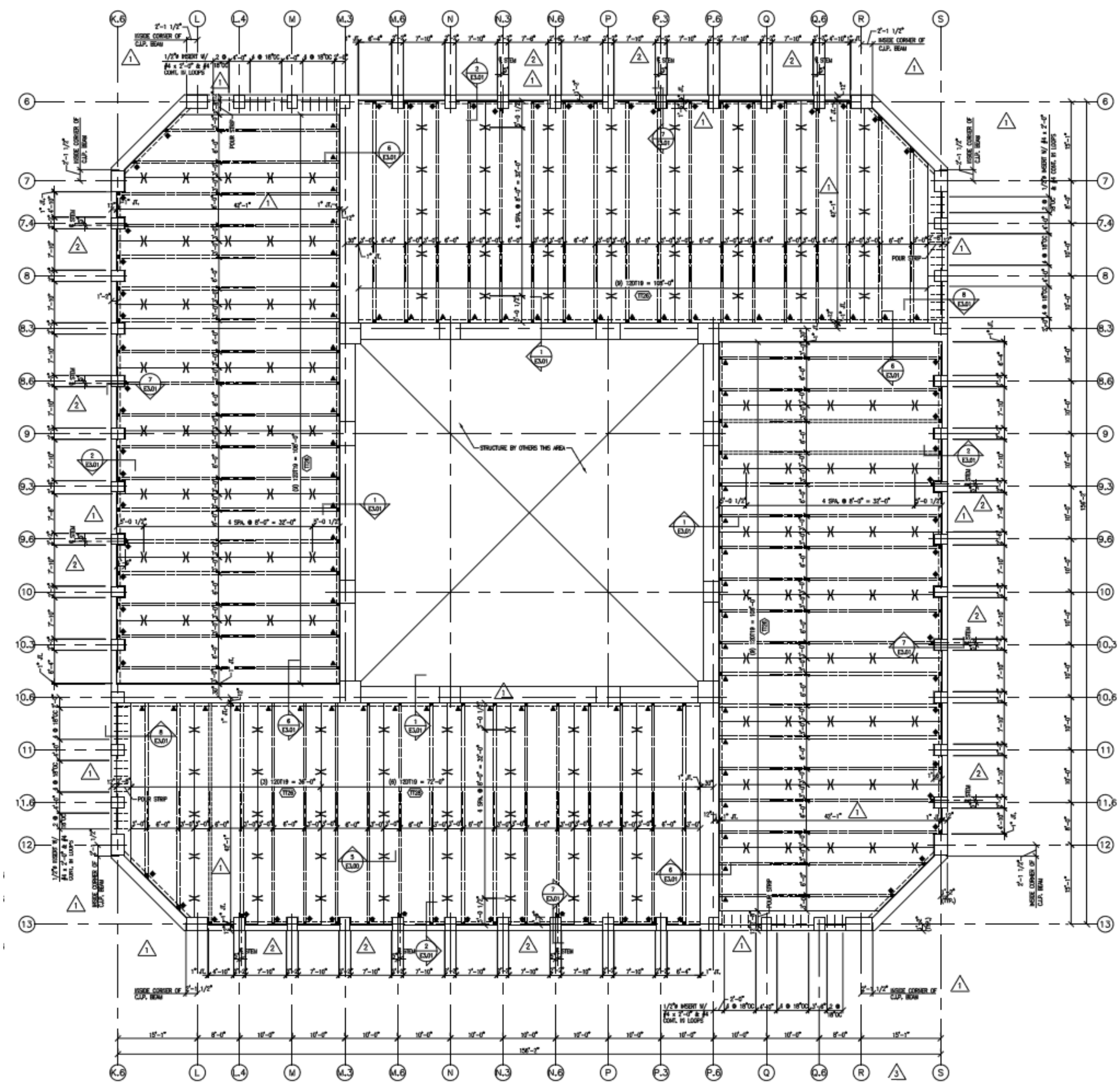

Figure 2 Double Tee Framing Plan - Tower

Both the office tower and podium use 12-ft-wide lightweight concrete precast, prestressed double tees with a lightweight concrete topping for their flooring system. The double tees were produced by Prestress of the Carolinas in Charlotte, NC. Double tees are used for all floors through the 45th story. The top three floors are framed with structural steel, creating a "window" or what some have described as a "handle" signature at the top of the building. Figure 3 shows the top portion of the tower as the structural steel "handle" is being erected. Note that the highest floors using concrete frame and double tees are still visible in this photo.

Figure 3 Duke Energy Center May 18, 2009
Photo courtesy of James Willamor

The tower features a 70 ft x 70 ft cast-in-place shear-tube core, with a 160 ft x 160 ft cast-in-place perimeter frame structure. TRC Worldwide Engineering in Brentwood, TN, evaluated several systems before choosing the cantilevered punch tube system for the 160-ft square structure. Self-climbing metal forms were used to place the tube concrete. "A tube sticking straight in the air is very strong," says Tommy Hagood, engineer of record and principal in charge for TRC[2]. This system is very rigid and acts as a shear wall and rigid frame combination. This eliminates the need for shear walls in the core area of the building and creates a more open design. The core is designed only for gravity loads and it houses the elevators, stair wells, utilities, etc. for the tower. Both seismic and wind loads controlled the lateral design for the exterior columns. An exterior cast-in-place frame takes the lateral wind and seismic loads. Columns were placed at 10 ft on center around the building. All of the cast-in-place concrete, including the lightweight concrete topping, was supplied by Concrete Supply Company of Charlotte, NC.

The lightweight concrete double tees spanned 43 ft from the exterior frame to the core. Britt Peters and Associates, Greenville, SC, designed all the double tees. Principal Edward Britt recommended the use of lightweight concrete for the double tees and the cast-in-place topping slab to reduce the volume of concrete. "To achieve a two-hour fire rating, the greater fire resistance of lightweight concrete allowed us to reduce the floor thickness of the cast-in-place topping by one inch. That is a big building. One inch added up to a lot of concrete and huge savings" said Mr. Britt.

Mr. Frankie Smith, Plant Manager for Prestress of the Carolinas, said "The double tee system allowed [the contractor] Batson-Cook to complete a floor every four days. They used 32-in.-deep double tees in the tower and podium up to the ninth floor. Starting with the tenth floor of the tower, the double tees were only 19 in. deep." The majority of the double tees had a design strength of 6,000 psi, but some of the beams were designed with up to 9,000 psi. "All of the lightweight concrete made strength," according to Mr. Smith, who added that "All the 9,000 psi concrete broke near 12,000 psi." Asheville, NC-based Southern Concrete Materials, who has a concrete batch plant adjoining the Prestress of the Carolinas plant, supplied all the lightweight concrete for the double tees.

UNUSUAL APPLICATION FOR DOUBLE TEES

The Duke Energy Center tower is thought to be the tallest building using double tees for the flooring system. Batson-Cook Construction is the building's general contractor. According to Batson-Cook Project Executive Randy Thompson, "There are not many [high rise] buildings that use them, but in this particular case, and after evaluating all of the different structural types that we could use, that turned out to be the most cost effective, and it minimized the schedule[3]."

Double tees are most commonly seen in parking structure construction. Parking garages typically require long span construction with a framing system of beams spanning approximately 60 ft across parking spaces on each side of a center driving aisle. This is the preferred garage layout because most drivers have a difficult time maneuvering around and parking next to interior columns. Also, people feel more secure in long span garages because they are usually more open and better lit[4]. Constructed in 1961, the Beverly Hilton Parking Structure, a five-story, 400-car parking garage, featured prestressed lightweight concrete double tees. Long spans eliminated columns in parking areas while the lightweight aggregate concrete minimized seismic and gravity loading. Durability was ensured by using 6,500 psi concrete. The result was an open, airy design that maximized the parking layout. The facility features 8-ft wide double tees, L spandrels, inverted tee beams and 4-story tall precast columns. Although built more than 40 years ago, it has been well maintained and retains its pleasing appearance to this day. The design was the forerunner for thousands of structures to come that have been built throughout North America using the same basic components[5].

Precast, prestressed concrete double tees offer remarkable strength for long spans, design flexibility, durability and excellent fire resistance. They have occasionally been used for bridge girders. On some bridges, the double tees are transversely post-tensioned side-by-side. Other typical building uses for double tees include water/wastewater treatment plants, food processing plants, heavy industrial buildings, warehouses, indoor pools and gymnasiums.

In 1966, Chancery Hall, Edmonton, Alberta, was Canada's first major multi-story building using a precast, prestressed concrete structure. The design concept soon was duplicated with buildings in Colorado, Oklahoma, Texas, North Carolina and Florida including the Gulf Life Insurance Building in Jacksonville, FL. At the time of its construction in 1969, the 27-story Gulf Life Tower was the tallest building in Jacksonville, FL. It included a six-level parking structure for 1,100 cars. It was unique for its time due to its use of an all-precast, white concrete framing system made up of individual precast elements that were post-tensioned together at each level and at all four sides to create 150-ft-long beams. The beams had two 50-ft cantilevers and a 50-ft center span that were supported on hollow white precast columns. After erection, the columns were filled with cast-in-place concrete to tie the system together. The floor system consisted of double tees and inverted tee beams with a cast-in-place center core[5].

Figure 4 Gulf Life Tower, Jacksonville, FL

LIGHTWEIGHT CONCRETE BENEFITS

REDUCED WEIGHT

Lightweight concrete made with rotary kiln expanded aggregate offers many benefits in almost all structural applications, the most obvious being reduced weight. Reduced weight allows savings in the structural frame itself and especially in the foundations. The reduced weight also reduces the seismic loadings for design; this reduction in lateral force requirement can be of importance, not only in the structural frame, but also in the connection details and the foundations[6]. Reduced weight also facilitates transportation of precast prestressed elements. Since maximum hauling weights are limited on public roads, use of lightweight concrete may make it possible to haul a larger unit. Many precast producers use lightweight concrete to allow them to haul two double tees instead of just one. Similarly, on construction projects where crane capacities are limited, use of lightweight concrete permits larger single elements to be lifted and set into place.

INTERNAL CURING

Absorbed water contained in lightweight aggregate provides water for internal curing of concrete. This allows better hydration of the cementitious materials as moisture is slowly released from the reservoirs of absorbed water contained within the pores of the lightweight aggregate. The benefits of internal curing are increasingly important when supplementary cementitious materials, (silica fume, fly ash, metokaolin, as well as the fines of lightweight aggregate) are included in the mixture. It is well known that the pozzolanic reaction of finely divided alumina-silicates with calcium hydroxide liberated as cement hydrates is contingent upon the availability of moisture. Additionally, internal curing provided by absorbed water minimizes the “plastic” (early) shrinkage due to rapid drying of concretes exposed to unfavorable drying conditions[7].

GREATER FIRE RESISTANCE

Lightweight concrete has demonstrated greater fire endurance than equal-thickness members made with normalweight aggregates. Therefore, lightweight concrete typically offers significant savings on a project that calls for fire rated floor, roof and wall assemblies by reducing the thickness of an element to achieve the same fire rating, as was noted by Mr. Britt in the design of the Duke Energy Center Tower. Superior performance of lightweight concrete is due to a combination of lower thermal conductivity (lower temperature rise on unexposed surfaces), lower coefficient of thermal expansion (lower forces developed under restraint), and the inherent thermal stability developed by aggregates that have been already exposed to temperatures greater than 2000 degrees F during the rotary kiln expansion process[8].

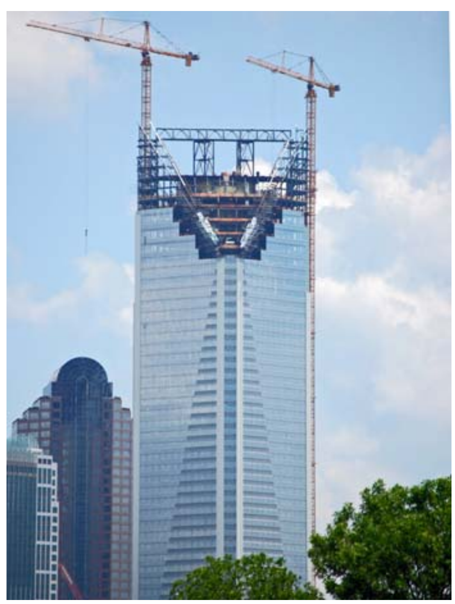

Figure 5 Duke Energy Center May 31, 2009
Photo courtesy of James Willamor

CONCLUSION

The use of lightweight concrete precast prestressed double tees field-topped with lightweight concrete on the 48-story Duke Energy Center office is an unusual design that helped speed up construction by eliminating any need for shoring. The double tees span 43 ft from the core to the perimeter (without columns) creating open floors and providing design flexibility in office layouts. The use of lightweight concrete for the double tees and their topping allowed a floor thickness reduction of one inch resulting in a significant reduction in the quantity of concrete required for this project, which in turn resulted in a significant cost saving to the owner.

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