HPCC in Brazilian Office Tower

High-performance colored concrete offers strength, thinner columns, more usable space, and aesthetics

BY PAULO HELENE AND CARINE HARTMANN

Fig. 1: Architectural rendering of the e-Tower

Currently nearing completion, the e-Tower in São Paulo, Brazil, employs high-performance (high-strength) colored concrete (HPCC) having an f'_c = 125 MPa. Employed within five columns for the first seven floors of the structure, the HPCC was batched in a normal commercial concrete plant, mixed by truck on the way to the site through heavy urban traffic, and placed 40 to 60 min after leaving the plant.

The experience represents a first-time use in Brazil of such a special concrete straight out of the research laboratory, with the objective of maximizing occupancy space, easing concrete placement, and thereby increasing productivity. At the same time, the coloring of the concrete columns achieves desired architectural effects in occupied portions of the structure and in its parking garage area.

At completion, e-Tower will be a modern office building (Fig. 1) offering 800 parking garage spaces, two excellent restaurants, a convention and business center, a semi-Olympic-sized swimming pool and fitness center, and a rooftop helicopter landing pad. It will also have an "intelligent" air conditioning system and provisions for energy and water system savings. Floor area for the completed 162-m-high, 42-story tower will be 52,000 m^2. Among the five tallest buildings in Brazil, the e-Tower can be considered a high-rise structure, or "skyscraper," under the international classification adopted by the Council on Tall Buildings and Urban Habitat.

BRAZILIAN CONCRETE BACKGROUND

Brazil is one of the most advanced nations in concrete technology in South America, having a tradition of constructing tall buildings over 100 m high. It is a long tradition. Seventy-four years ago, in 1929, Brazilian engineers designed the Martinelli Building, reputed to be the highest concrete tower in the world at the time with its height of 106 m above the streets of São Paulo. In 1960, they inaugurated the Palacio Zarzur Kogan concrete tower, the

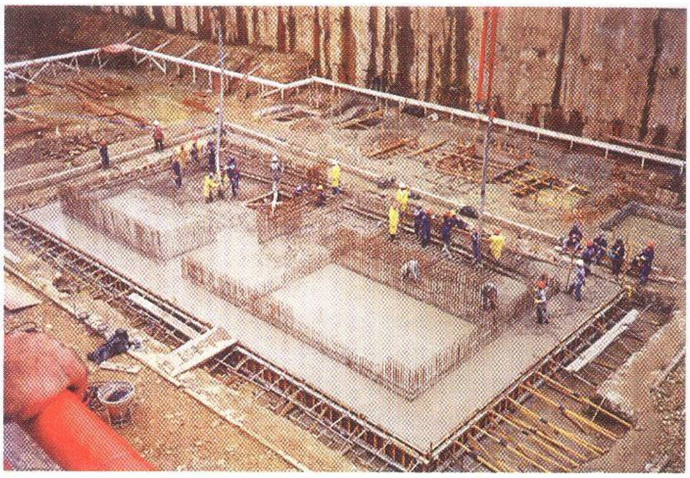

Fig. 2: The foundation block for the e-Tower required the addition of ice to the mixing water to help control heat of hydration

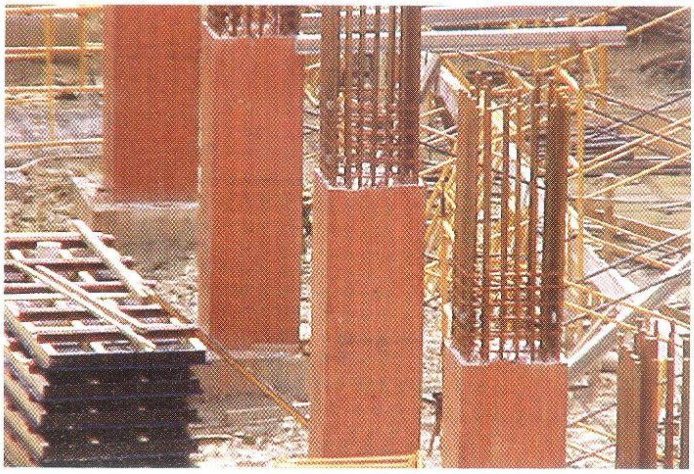

Fig. 3: Use of high-performance (high-strength) colored concrete (HPCC) columns permit slimness in design and construction, maximizing usable building area and providing an aesthetic touch

highest office building in the nation at the time, measuring 189 m high.

e-TOWER DESIGN AND CONSTRUCTION REQUIREMENTS

The e-Tower is supported on a single, large concrete foundation block (Fig. 2), 17 m wide x 28 m long x 2.8 m in depth, and cast with 35 MPa concrete. Ice used in the mixing water controlled the heat of hydration, achieving placement temperatures around 15 °C as against ambient 25 °C.

Each of the five main columns carried by the foundations take about 2500 tonne loading and have less than 0.42 m^2 of cross section to maximize occupancy and vehicular parking space at lower levels.

To meet these dimensional limits, the team of Munir Abbud, for the owner; Jorge Batlouni, engineer for the contractor, Tecnum; Ricardo França, structural engineer; Eliron Souto for the ready-mixed company, Engemix; and one of the authors, Paulo Helene, accepted the challenge to design an appropriate high-performance concrete.

The team sought the highest strength concrete ever specified in Brazil for a concrete structure. This had to be supplied by mixer truck from a normal concrete plant in São Paulo. The challenge became more interesting when project architects, Aflalo and Gasperini, decided to add color to the high-strength concrete columns, reaching record-breaking heights with colored concrete.

TECHNICAL AND ECONOMICAL ASPECTS

Designers chose high-strength concrete as an alternative dictated by technical and economic issues governing the configuration of the e-Tower, and the critical need to reduce column dimensions within the first five floors (Fig. 3). Colored high-strength concrete was employed on columns within floors, four of which are located in four underground parking garage floors and in elongated columns within the main entrance floor and two additional floors.

Overall, the use of HPCC is resulting in a 53% savings in concrete volume, and 3% in total costs. The material also permitted room for four additional vehicular spaces on each of the four parking garage floors, adding to potential building revenue.

CONCRETE MATERIALS

In selecting materials, the following criteria had to be considered: quality of portland cement and aggregate; cement admixtures and admixture-admixture compatibility; suitability of the pigment in providing long-lasting durable color and not inhibiting concrete strength; and local availability and cost.

All concrete materials were drawn from São Paulo and environs. Local coarse aggregate consisted of a sound and strong basalt having a maximum nominal particle size of 19 mm, 3.02 kg/m^3 density, and a fineness modulus of 6.91. Quartz sand served as fine aggregate, maximum nominal size of 2.4 mm, 2.67 kg/m^3 density, and a fineness modulus of 2.04. The portland cement used is a Brazilian high-initial-strength Type V similar to ASTM C 150 Type III, with the addition of about 23% blast-furnace slag, 13% silica fume or 15% metakaolin, 4% red inorganic pigment for color, 1% high-range water reducer based on polycarboxylate, and a 0.45% admixture for hydration control and set retardation. The nature of the HPCC mixture permitted almost 3 h of highly productive placement for all of the five colored columns within a floor.

CHOOSING COLOR

The architect chose color for aesthetics, but the contractor also employed color for identification and differentiation of the HPCC when it arrived at the construction

TABLE 1:
MIXTURE PROPORTIONS OF THE HIGH-PERFORMANCE COLORED CONCRETE USED IN THE E-TOWER'S COLUMNS

Materials	Mixture proportions, kg/m³	Observation
Cement	460 cement + 163 slag	ASTM C 150 Type III + slag
Silica fume or metakaolin	93	—
Fine aggregate	550	Quartz
Coarse aggregate	1027	Basalt
Pigment	25	Iron oxide
High-range water reducer	6.2	Polycarboxylate
Set retarder	3.2	Carboxylic acid
Water	135	Water-cementitious material ratio 0.19

Fig. 4: A slump between 140 and 200 mm proved acceptable for workable HPCC

site to avoid mix-ups between HPCC and conventional concrete. Mineral iron oxide forms the basis of the HPCC's red color, and is supplied as a dry powder and added at the batching plant.

MIXTURE PROPORTIONING OF THE HPCC

Laboratory experiments required a total of 1.5 m³ of HPCC as against about 150 m³ in the construction of these 35 high-strength columns. There were many factors considered in proportioning the concrete mixture, such as early and final strength, temperature rise, high workability, mortar proportioning, and loss of slump. To meet all of the requirements, a number of concrete mixture proportions had to be developed and their compressive strengths and elastic moduli investigated to help select the most appropriate one. A slump between 140 and 200 mm proved acceptable for workability in the field (Fig. 4). Technicians cast test columns in both the laboratory and field during the 3 months before actual placement.

As of this writing, the concrete structure of the e-Tower has been completed and finish work continues. Color is limited to the lower floors as described, with column strengths above the lower levels being successively reduced until they reach 60 MPa and 40 MPa, according to location, in the last 10 floors. Table 1 lists the mixture proportions used in the colored concrete columns.

PLACEMENT AND CURING OF HPCC

The HPCC was truck-mixed from plant to job, with mixing continuing on site for a minimum of 8 min before slump testing and placement. Workers placed the HPCC into the formwork by crane and dump bucket (Fig. 5), consolidating the concrete with immersion vibrators. They removed the formwork after 72 to 96 h, to expose clean and even concrete surfaces—despite the close spacing of reinforcing bars. Also, the HPCC exhibited good cohesiveness, permitting free gravity casting of the columns from over the tops of column reinforcement on a floor.

Columns reached a floor-to-ceiling height of 5.5 m on the main floor of the building. Crews cast the tops of columns at junctions of slabs and beams on a subsequent day. Slab and beam concrete strength is 40 MPa, with each of these sections

TABLE 2:
SOME PROPERTIES OF HPCC COMPARED WITH MORE CONVENTIONAL 30 MPA STRUCTURAL CONCRETE

Properties		HPCC, f'_c = 125 MPa	Normal concrete, f'_c = 30 MPa
Compressive strength (ASTM C 39)	7 days	111 MPa	18 MPa
	28 days	125 MPa	36 MPa
	63 days	141 MPa	41 MPa
	91 days	155 MPa	44 MPa
Elastic modulus (ASTM C 469)	28 days	47 GPa	33 GPa
Flexural strength (ASTM C 496)	28 days	10.0 MPa	3.3 MPa
Carbonation depth at 28 + 63 days at 25 °C, RH 65%, CO_2 5%	91 days	0	28 mm
Water absorption, density, and pore volume (ASTM C 642)	Water absorption	0.35%	5.1%
	Water absorption after boiling	0.41%	5.8%
	Pore volume	1.0%	13.2%
	Pore volume after boiling	1.1%	15.1%
	Density	2500 kg/m^3	2320 kg/m^3
Capillary absorption (ASTM C 1403)	Capillary absorption, after 72 h	1.2 kg/m^3	12.0 kg/m^3
	Maximum internal ascension of water, after 72 h	0 mm	99.0 mm
Chloride ion penetration (ASTM C 1202)		43 C	8000 C
Ultrasonic pulse velocity (ASTM C 597)		4950 m/s	3250 m/s
Hammer test (ASTM C 805)		52	27

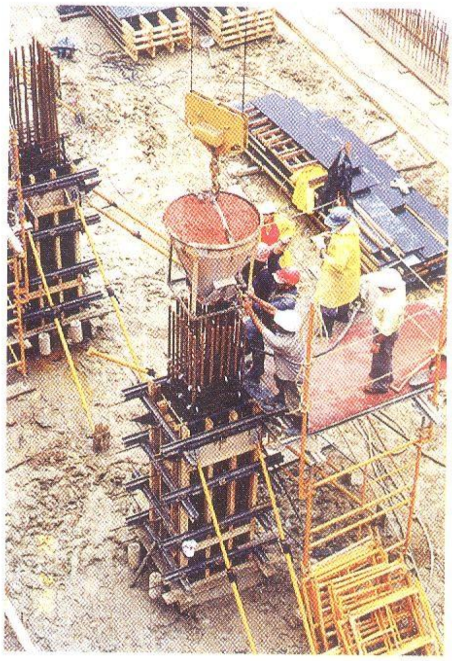
Fig. 5: A crane and dump bucket place HPCC into column formwork

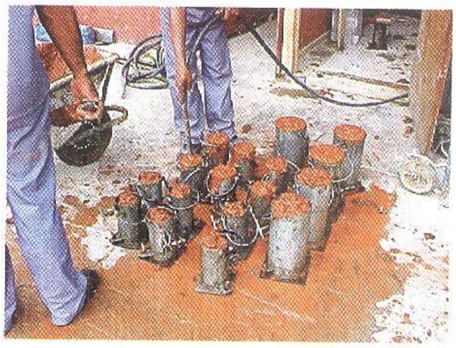
Fig. 6: Test cylinders, 100 x 200 mm and 150 x 300 mm, being prepared at the site

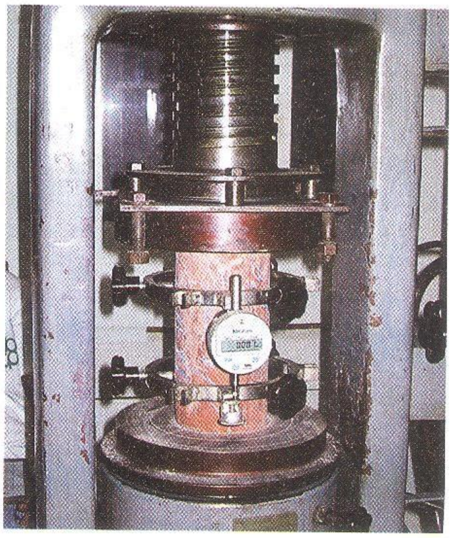
Fig. 7: Modulus of elasticity at 28 days tested out to 47.7 GPa with a standard deviation of 4.2 GPa and an 8.7% standard variation

cured by keeping formwork in place for a minimum of 72 h. It was necessary to keep curing until the compressive strength of the HPCC exceeded 15 MPa.[1] The HPCC has a water-cementitious material ratio (*w/cm*) of 0.19, and attained a compressive strength over 50 MPa when the formwork was removed, thereafter rendering any water curing unnecessary.

CONTROL OF HPCC

To control the quality of HPCC, normal investigations included slump testing, and cylindrical (100 x 200 mm and 150 x 300 mm) and cubic (150 mm on edge) specimens were cast for compressive strength, modulus of elasticity, and temperature observations as well (Fig. 6). The workability of HPCC, determined by slump test, was not a decisive factor because concrete slump could vary from 140 to 200 mm^2 and was also influenced by ambient temperature and relative humidity.

Investigators cast test specimens as the concrete was being placed in the structure, their sample concrete being taken directly from the discharge end of the truck hopper. Each concrete mixer truck was charged only halfway, carrying about 4 m^3 of concrete. All trucks were tested.

The HPCC's compressive strength f'_c, determined from 150 x 300 mm cylinders (ASTM C 39), reached 124.8 MPa on average after 28 days, with a maximum at 149 MPa and a minimum at 109.8 MPa. Standard deviation was 6.1 MPa and standard variation was 4.9%. The modulus of elasticity E_c (ASTM C 469) average at 28 days reached 47.7 GPa, with a standard deviation of 4.2 GPa and a standard variation of 8.7% (Fig. 7).

The HPCC installed in the e-Tower can be compared with the 30 MPa concrete also used in the complementary structure. Table 2 compares the concrete properties in the e-Tower to the complementary structure. The Brazilian Cement Association, which is promoting and stimulating the development and correct usage of high-performance concrete, performed the laboratory testing as an important partner in the project.

Major advantages of using HPCC in the e-Tower building can be summarized as follows:

- High strength providing structural security;
- High-early strength permitting early formwork removal;
- High durability;
- Easy and rapid project execution, with high productivity and no reworking;
- Lower concrete column creep;
- Higher modulus of elasticity and therefore less deformation; and
- Additional usable space in the final structure.

Table 2 provides a comparison of properties between the HPCC used and normal, or more conventional, concrete.

Results from both the fresh and hardened concrete proved excellent, and the project, as it reaches completion, can be considered a success. Adequate, applied concrete technology made these results obtained with HPCC possible, as did the rigorous materials selection process and excellent quality control. All were enabled by solid partnering between the selected concreting team.

Currently, high-performance concrete presents great opportunities to influence the architecture throughout South America, as well as the significance of the engineering profession in that region. Designing and constructing with consideration of life-cycle and maintenance costs and improving service life of concrete structures can maximize investment, save raw materials, and improve the self-esteem of the Brazilian people.

Acknowledgments

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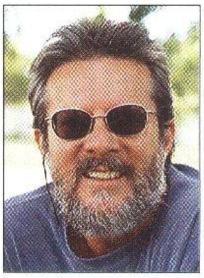

Paulo Helene, PhD, is Full Professor at the University of São Paulo, Brazil, and an ACI member since 1992. He is co-editor of ACI SP-187 (1999) and ACI SP-207 (2003), both about high-performance concrete. He has worked for 30 years in education, research, and consultancy on concrete materials and structures. Helene is also President of IBRACON (the Brazilian Concrete Institute); Deputy Chair of *fib* (CEB-FIP) Commission 5, "Structural Service Life Aspects"; and Chair of the Ibero-American Network on Concrete Structures Rehabilitation. He is a member of other concrete-related associations such as ASTM International, NACE, and IABSE.

Carine Hartmann has been a civil engineer since 1998 and is a specialist in civil construction. She is an MS and a PhD student at Polytechnic School University of São Paulo, as well as a member of IBRACON, the Brazilian Concrete Institute.