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How the BIG DIG IS TRANSFORMING BOSTON

How the Big Dig Is Bost

Fifteen-year project is considered one of the most innovative engineering feats in U.S. history

When the Central Artery that knifed through the center of downtown Boston opened in 1959, the highway could adequately handle some 75,000 cars per day. Through the years, the number skyrocketed to upwards of 200,000 daily vehicles, creating one of the most congested highways in the country. ■ Traffic snarled for 10 hours per day and the accident rate surged to four times the national average for urban interstates. Similar problems beset the two tunnels under Boston Harbor. Moreover, the Central Artery displaced 20,000 residents when it was built, cutting off Boston's North End and waterfront neighborhoods from downtown. ■ Worse, projections forecast that by 2010, stop-and-go traffic jams would stretch up to 16 hours a day.

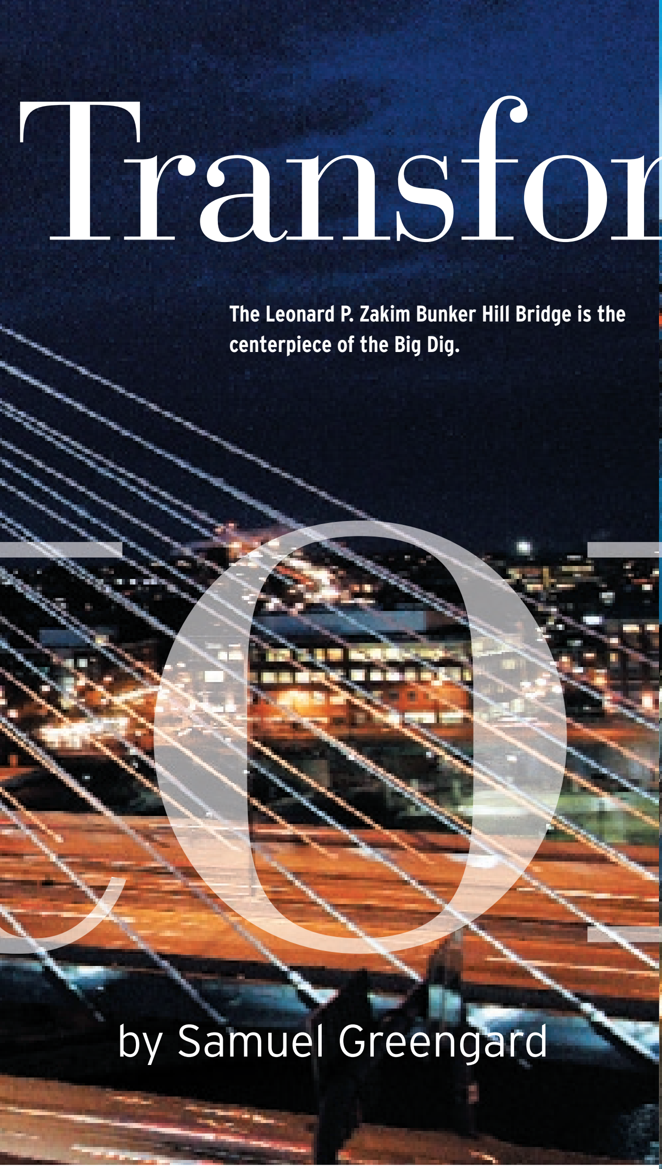
Something had to be done. The main artery and its secondary tributaries were hemorrhaging, bleeding the life out of the city's heart—economically and from a quality-of-life perspective.

But all that began to change in 1991 when construction crews broke ground on the Central Artery/Tunnel Project, commonly known as the Big Dig. The surgery was an overwhelming success. Today Boston's traffic flows smoothly, neighborhoods are once again connected and the economic impact of the project has pumped new life into the heart of downtown.

The scope of the project is nothing less than breathtaking. The Big Dig is larger in size than the Panama Canal; engineers had to support existing high-rise buildings, subways and other infrastructure while constructing tunnels and managing traffic flow for more than 200,000 motorists a day.

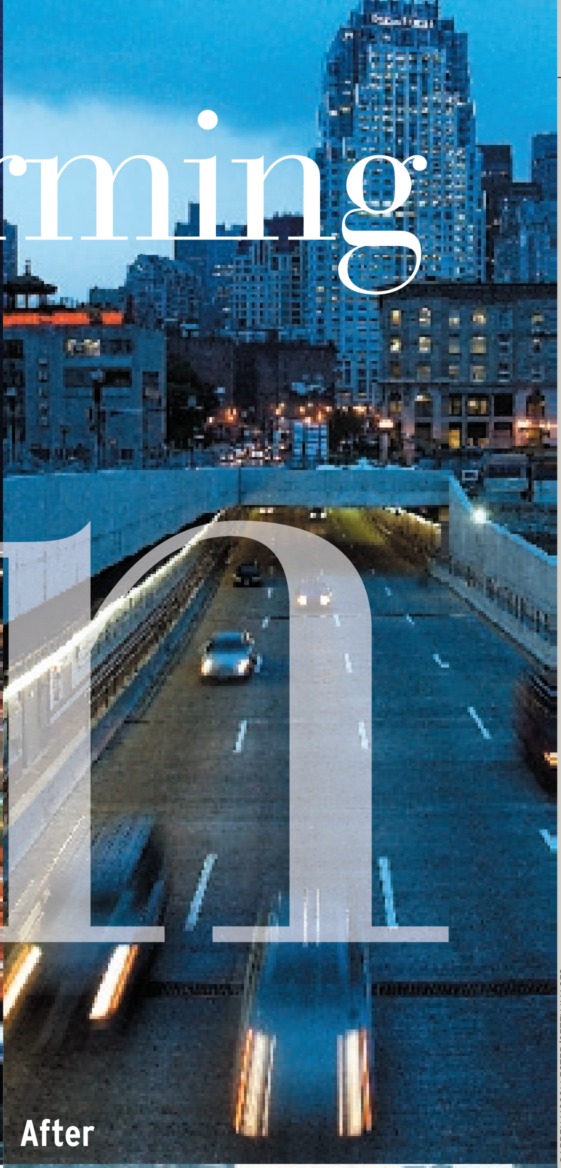
Along the way, project engineers faced formidable challenges. For example, Boston's weak soil couldn't support a tunnel, and engineers had to use construction methods that had never before been attempted. Although the Big Dig suffered many of the cost and political problems associated with modern-day

Transforming



The Leonard P. Zakim Bunker Hill Bridge is the centerpiece of the Big Dig.

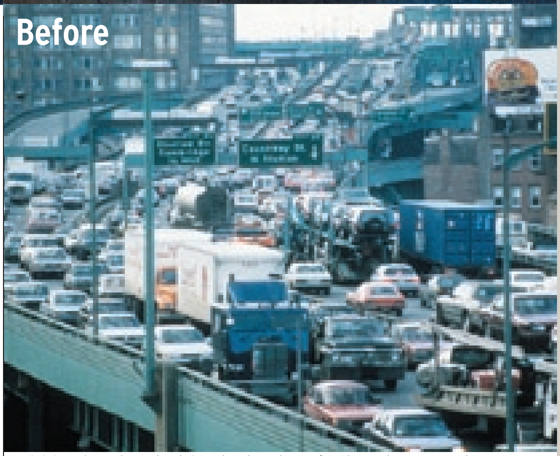
by Samuel Greengard



DARREN MCCOLLESTER/GETTY IMAGES

megaprojects—the price tag swelled from $2.6 billion to more than $14.6 billion—it has succeeded in easing Boston's famous traffic tie-ups.

According to the Massachusetts Turnpike Authority (MTA), the project has trimmed the average trip through the center of Boston from 19.5 minutes to 2.8 minutes, reduced rush-hour backups from 10 hours per day to a couple of hours per day and added 300 acres of new parks and plazas. "The project has made Boston a more viable city with a great future," states Richard Dimino, president and CEO of A Better City, an organization that promotes business interests in Boston.



MASSACHUSETTS TURNPIKE AUTHORITY

1989: The elevated Central Artery in downtown Boston experienced nine hours of gridlock a day.

Clearing Congestion

The Big Dig is a story of vision, innovation and persistence. The genesis of the project dates to the early 1980s. At the time, Boston faced near-gridlock traffic and a realization that the problem was only going to get worse. A mile-long stretch of raised highway included 27 on-ramps and off-ramps, which contributed to serious slowdowns and dangerous driving conditions and would eventually lead to $500 million a year in additional gasoline, road repairs and related costs. "It was clear that something had to be done," Dimino recalls.

Unfortunately, Boston lacked space to widen its central highways or build new expressways through the city. Compounding matters, most of the city's residents already considered the old Central Artery—a.k.a. the Green Monster—an eyesore and ongoing problem. Its construction cut off Boston's

Big Dig Engineering Firsts

- The world's widest cable-stayed bridge, the Leonard P. Zakim Bunker Hill Bridge, carries 10 lanes of traffic and can withstand 400 mph winds.
- The deepest underwater tunnel in North America. The Ted Williams Tunnel in East Boston reaches nearly 100 feet below the surface of Boston Harbor.
- An innovative ground-freezing technique stabilized Boston's weak soil during construction. Approximately 2,000 pipes eight feet apart, were filled with a saltwater coolant solution chilled to minus 30 degrees Fahrenheit.
- The most extensive geotechnical investigation, testing and monitoring program in North America prepared the way for excavation, tunneling and construction.
- One of the largest tunnel ventilation systems in the world used 151 infrared sensors controlling 140 fans used to blow fresh air in and exhaust fumes out.
- The largest use of slurry wall modules in North America allowed crews to conduct excavation work within a confined space without disrupting transportation systems directly above.

The Timeline

1982: Work begins on Final Environmental Impact Statement/Report (FEIS/R).

1985: FEIS/R filed and approved in early 1986.

1986: Bechtel/Parsons Brinckerhoff begins work as management consultant.

1987: Congress approves funding and scope of project. Building acquisition and business relocation process begins; no private homes are taken.

1988: Final design process under way. Exploratory archaeology begins.

1989: Preliminary/final design and environmental review continue.

1990: Congress allocates $755 million to project.

1991: Federal Highway Administration issues Record of Decision, the construction go-ahead. Final FEIS/R approved. Construction contracts begin to be advertised and awarded. Construction begins on Ted Williams Tunnel and South Boston Haul Road.

1992: More than $1 billion in design and construction contracts under way. Dredging and blasting for the Ted Williams Tunnel continues. Downtown utility relocation to clear path for Central Artery tunnel construction begins. Archaeologists find 17th- and 18th-century artifacts at a North End dig.

1993: South Boston Haul Road opens. All 12 sections of the Ted Williams Tunnel are placed and connected on harbor floor.

1994: Charles River Crossing revised design and related FSEIS/R approved. New set of loop ramps open in Charlestown.

1995: Ted Williams Tunnel opens to commercial traffic.

1996: Downtown slurry work under way for I-93 tunnels.

1997: Overall utility work 80 percent complete.

Twelve steel binocular immersed tubes, each the size of a football field, make up the Ted Williams Tunnel that crosses Boston Harbor.

Cars and trucks travel north through the new I-93 tunnel.

North End and waterfront neighborhoods from downtown, forever changing the look of the city and, many contend, damaging its economy.

The idea of tunneling under the city and its waterfront grew out of the realization that there wasn't a more practical way to solve Boston's transportation problems. Fred Salvucci, then secretary of transportation for the Commonwealth of Massachusetts and now a senior lecturer and researcher at the Massachusetts Institute of Technology, believed it was absurd to "simply rebuild a 50-year-old mistake so that it could hang around for another 50 years, polluting and obstructing the economic growth of the city." He also recognized that total closure of existing roadways was not an option.

After studying the city's transportation problems in the early 1980s, traffic planners recommended a $2.6 billion initiative that would ultimately grow into a comprehensive quilt of 140 construction projects. Construction would span more than a decade and redefine modern highway engineering. Urban planners and engineers could not have foreseen what a complicated and challenging project the Big Dig, approved in 1987, would become. It would require new and untested engineering methods, along with equal doses of creativity and persistence.

"The Big Dig harnessed some of the best technical minds in the industry and confronted some

> Removing the raised roadway has reinvented and re-knitted the city. It has helped create an attractive urban environment…"
>
> *MICHAEL BERTOULIN*
> *PARSONS BRINCKERHOFF*

of the most difficult conditions highway engineers could ever face," explains Michael Bertoulin, vice president of Parsons Brinckerhoff, part of the construction management team on the Big Dig. "The challenges associated with keeping the city running during the height of construction were enormous."

Deep Thinking

The first phase of the project involved tunneling under Boston Harbor using the immersed tube tunnel (ITT) method. In 1991, a dredger known as the "Super Scoop" began dredging 900,000 cubic yards of earth. This enabled work crews to begin laying steel ITT sections across the harbor. Each of the ITTs consisted of a 15,000-ton composite structure composed primarily of concrete and a pair of 40-foot steel tubes joined side by side and extending 330 feet. By 1992, the 12 tunnel sections—built by Maryland-based Bethlehem Shipbuilding—began arriving at the site. Crews then added concrete to transform the steel hulks into structures that would serve as the highway's foundation.

In 1993, a catamaran barge began towing the tunnel sections into position. Each of the tubes had to be lowered within a fraction of an inch from their designated location in order to ensure a watertight seal. Workers used global positioning devices and lasers to position pieces of the tunnel within the murky waters of Boston Harbor. Working 100 feet below the surface—the Big Dig was the deepest tunneling project in the history of North America—workers finished connecting the 33-ton sections in 1995. By December of that year, the newly christened Ted Williams Tunnel opened on budget and on schedule.

> "It is a terrific example of engineering excellence and innovation. It will be a case study for building large public projects."
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> *ABBIE R. GOODMAN*
> *ACEC/MASSACHUSETTS*

DARREN McCOLLESTER/GETTY IMAGES

> "The project has made Boston a more viable city with a great future."
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> *A BETTER CITY*

MASSACHUSETTS TURNPIKE AUTHORITY

But the Big Dig had only just begun. In order to connect the tunnel to I-90, engineers had to build another tunnel under Boston's 400-foot-wide Fort Point Channel. The eight-lane highway would have to cross over a subway line, run adjacent to a manufacturing plant and large post office and run beneath commuter rail lines. To extend I-90 under the tracks and across the channel, engineers were forced to push the limits of existing technologies. The process involved a combination of imaginative concrete box ITTs, massive ground modification and "jacked" highway tunnel boxes underneath an operating rail corridor.

Engineers turned to soil mixing—a Japanese technique—to modify the pudding-like soil on the bank of the Fort Point Channel. Using heavy blades and rotors, construction workers drilled down approximately 130 feet and mixed in cement to create a material that would support 300 to 1,000 pounds per square inch (PSI). After solidifying an area and creating a mass gravity wall, excavation commenced adjacent to existing commuter rail lines at the channel edge. The area became the interface between the ITTs and jacked tunnels. However, low bridges in the channel prevented crews from building the ITTs off-site. Instead, engineers created a 60-foot-deep and 1,000-foot-long dry dock, otherwise known as a casting basin. The basin held six different concrete sections during construction.

The challenges didn't stop there. Crews had to float the 27-foot-high sections (which measured up to 414 feet long and 174 feet wide) into place. Construction teams also couldn't build all the structures at the same time—meaning the basin had to be filled and drained more than once. Two of the sections served as the foundation for ventilation structures on their roof—thus making the

1998: Peak construction years begin. Construction begins on the Charles River Crossing.

1999: Overall construction 50 percent complete. New Broadway Bridge opens. Leverett Circle Connector Bridge opens.

2000: Nearly 5,000 workers employed on the Big Dig.

2001: Overall construction 70 percent complete.

2002: Leonard P. Zakim Bunker Hill Bridge completed.

2003: I-90 Connector from South Boston to Rt. 1A in East Boston opens in January. I-93 Northbound opens in March. I-93 Southbound opens in December.

2004: Dismantling of the elevated Central Artery (I-93). Opening of the tunnel from Storrow Drive to Leverett Circle Connector, which provides access to I-93 North and Tobin Bridge.

2005: Full opening of I-93 South. The opening of the completely renovated Dewey Square Tunnel, including new exit and entrance ramps. Opening of the two cantilevered lanes on Leonard P. Zakim Bunker Hill Bridge. Opening of permanent ramps and roadways at I-90/I-93 interchange and in other areas.

2006: Reached substantial completion of the Central Artery/Tunnel Project in January. Spectacle Island Park opens to the public.

2007: Restoration of Boston city streets. Continued construction of the Rose Kennedy Greenway and other parks. Construction on development parcels continue after the Central Artery/Tunnel Project is finished.

SOURCE: Massachusetts Turnpike Authority.

By the Numbers

- **Amount of dirt excavated:** 15 million cubic tons.
- **Concrete used to replace the dirt:** 3.8 million cubic feet.
- **Steel used:** 26,000 linear feet.
- **Traffic management system:** 400 video cameras, 130 electronic message signs, 30 infrared height detectors, six emergency response systems.
- **Reduction in air pollution due to central artery project:** 12 percent citywide.
- **Maximum number of construction workers on project:** approximately 5,000.
- **Number of construction contracts executed:** 109.
- **Underground utilities relocated:** 29 miles of gas, electric, water, sewer, telephone and other lines managed and maintained by 31 companies.
- **Deepest point:** 120 feet at Dewey Square, where it passes beneath the Red Line subway.
- **New parkland:** 300 acres (27 acres reclaimed from the elevated highway).
- **Toxic contaminants hauled away:** 435,000 cubic yards of soil and other debris.

The old elevated High Bridge over the Charles River is demolished in early 2004.

MASSACHUSETTS TURNPIKE AUTHORITY

process of transporting them, and balancing their weight within the water, even more complex.

Using remote control cameras, engineers positioned the pieces and connected them like giant Lego blocks.

Constructing the last link between the ITT and I-90 created another challenge. Engineers had to dig under commuter rail lines carrying more than 150 trains and 100,000 passengers a day, without disrupting the tracks. Once again, workers faced the problem of soft soil that couldn't support tunneling. Any attempt to remove the soft soil under the tracks risked derailing the entire project. That's when one contractor proposed a new and radical solution: Freeze the soil during the tunneling process using 2,000 pipes located eight feet apart, each filled with a brine refrigerant solution chilled to minus 30 degrees Fahrenheit. "It was like creating a manmade permafrost," Bertoulin says. Workers mined 18 inches into the frozen soil, creating a void using the tunnel-jacking process. The tunnel jacking required 10,000 PSI to move the 35,000-ton sections at a rate of three feet per day until they were in place. The process took three years to complete, but left the structures on the surface untouched.

In September 2001, a massive leak occurred in the section where the land and sea tunnels met. Rapidly rising water inundated expensive cranes and other equipment and made the tunnel impassable. Although crews began working on the problem immediately, it took divers nearly eight weeks to identify and plug the leak. By then, the opening of the tunnel was delayed by four months.

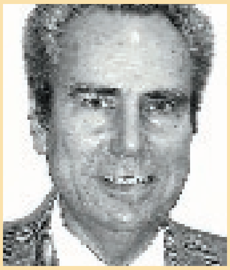
Driving Results

The final piece of the project was the engineering of the tunnel beneath I-93. To clear space for the underground highway, engineers had to build corridors to relocate pipes, cables and other infrastructure that fills virtually every square inch of subterranean Boston. At one point, they had to dig underneath three levels of subterranean transportation systems—subway lines, heavy rail and a bus station—and create a tunnel space only 36 inches beneath the subway.

"Essentially, we had to create a parallel set of walls with huge crossbeams beneath the existing raised structure in order to build the tunnel. The ground had to support both the existing steel and concrete structure and the tunnel box," says Frank Leathers, a geotechnical engineer and president of GEI Consultants, Inc., which designed one section of the slurry walls for the project. Prior to the Big Dig, Leathers says, the slurry wall module building method had never been attempted on such a large scale.

Project planners also recognized the need to replace a deteriorating three-lane double-decker bridge over the Charles River used to connect the tunnel to the interstate. Further complicating the project, engineers decided it was necessary to build around the existing bridge structure so that traffic continued to flow during construction. Today, the $100 million cable-stayed Leonard P. Zakim Bunker Hill Bridge, the widest asymmetrical bridge ever built, carries 10 lanes of traffic—eight through the legs of twin towers

KEY PLAYERS



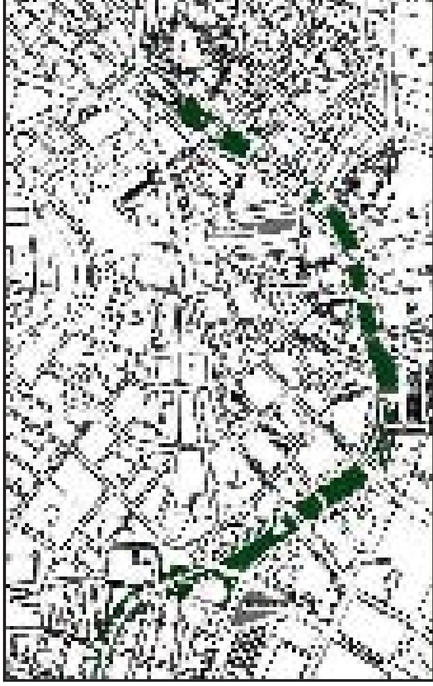
FRED SALVUCCI
An engineer and former Massachusetts transportation secretary (1983–1990), he is credited with first envisioning the concept of the Big Dig and generating the project's initial financial and political support.

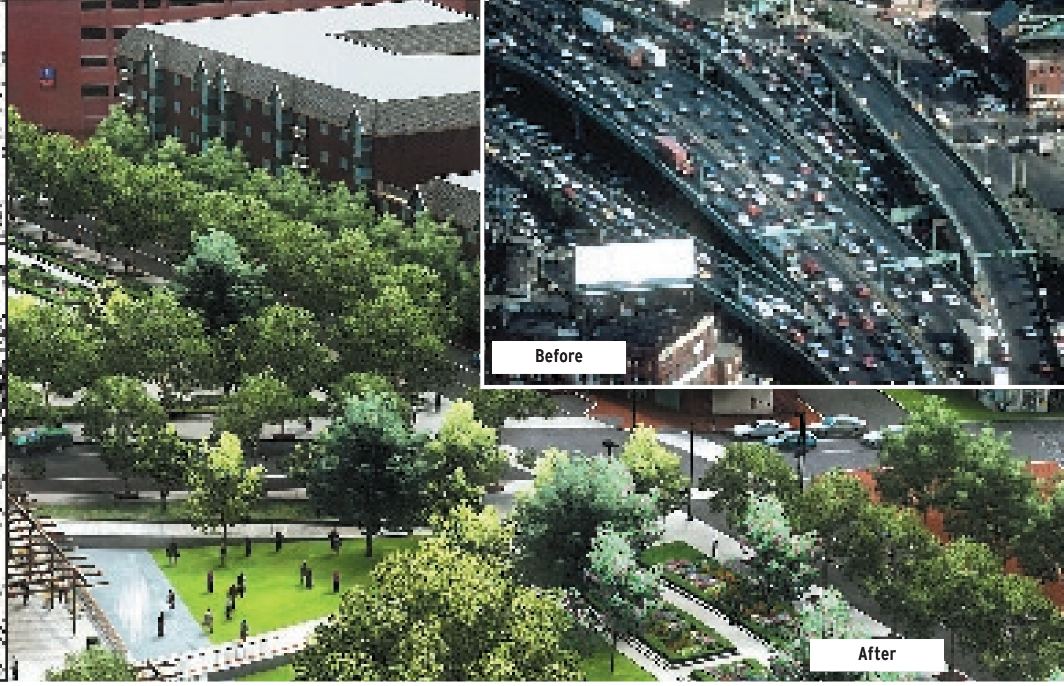
SALLY PERRIN
Former deputy project manager for the Bechtel/Parsons Brinckerhoff team, she oversaw environmental mitigation, real estate and traffic management as they prepared for construction.

JOHN KENNEDY
Senior principal at Vanasse Hangen Brustlin, Inc., he designed the traffic management plan that maintained safe and efficient traffic operations during the 15-year Big Dig construction period.

PAUL HARRINGTON
Director of structural division at Fay Spofford & Thorndike, Inc., he developed the underpinning (foundation support) system that allowed tunnel construction to proceed without affecting existing transit/rail systems or surface structures.

SENA KUMARASENA
HNTB associate vice president, he served as project engineer and project manager during the design and construction of the Leonard P. Zakim Bunker Hill Bridge, the widest cable-stayed bridge in the world.





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Once a mass of elevated highway ramps, North End Park, part of Boston's Rose Fitzgerald Kennedy Greenway, will open in spring 2008 (top right). A series of 14 parks will cut through the city from Causeway to Kneeland Streets (above).

supporting the bridge and two cantilevered on the east side. It is designed to withstand 400 mph winds and a magnitude 7.9 earthquake.

Throughout the Big Dig, engineers had to keep cars flowing. "It was essential to understand how every aspect of the project would affect traffic patterns and driving conditions," explains John J. Kennedy, a traffic consultant with Watertown, Mass.-based Vanasse Hangen Brustlin, Inc. "We had to make sure that total coordination existed among various contractors and government agencies." Engineers rerouted traffic daily and, almost without exception, improved traffic flow during the construction phase, he recalls.

At its peak, the Big Dig employed nearly 5,000 construction workers. The management team of Bechtel Corp. and Parsons Brinckerhoff oversaw 38 design contracts and 119 construction contracts involving 109 companies. "It was a very schedule-driven project that required tremendous synchronization of people and resources," explains William J. Rizzo, former CEO and president of Tetra Tech Rizzo, which handled the engineering for two interchanges along I-93. "We had people from different companies—with entirely different cultures—working together [in a joint venture] to achieve a mutual goal."

On Jan. 18, 2003, officials raised the sign on I-90 and opened the last section of the 3,462-mile link to Seattle. A year later, workers dismantled the old I-93 structure and began replacing it with 300 acres of parks and plazas. "Removing the raised roadway has reinvented and re-knitted the city," Bertoulin says. "It has helped create an attractive urban environment that otherwise wouldn't have been possible."

Leaving a Legacy

Though the Big Dig has distinguished itself as an engineering marvel on par with the Panama Canal, Europe's Chunnel and the Hoover Dam, its accomplishments are not without controversy. At $14.6 billion, the Big Dig is the most expensive highway project in history and its eventual price tag—more than $12 billion above the initial estimate—has left some citizens and government officials angry and dissatisfied. The Massachusetts Turnpike Authority filed a $146 million breach-of-contract lawsuit in 2004 over cost increases and other lingering issues, including outstanding legal and insurance claims, with the Commonwealth of Massachusetts. ACEC/Massachusetts is now sorting through the mess. "It's a complex matter that will take years to resolve," Leathers says.

The project also endured its share of tragedies. Sadly, four workers died while building the tunnels and infrastructure. In July 2006, a motorist passing through the I-90 connector tunnel was killed after bolts failed and a 12-ton concrete slab fell atop her vehicle. The tunnel was closed for five months while workers replaced the panel's anchor. Later, Thomas F. Reilly, attorney general for Massachusetts, filed 15 lawsuits against firms that he accused of negligence in the ceiling collapse.

Nevertheless, the Big Dig left a remarkable imprint on Boston. With 7.8 miles of highway and 161 total lanes, it has greatly reduced traffic, accidents and air pollution. A new park—the Rose Kennedy Greenway—will accommodate joggers, picnickers, workers on lunch breaks, local residents walking dogs, and children at play. And the Boston waterfront, now reconnected to the city, is enjoying an economic boom.

"It is a terrific example of engineering excellence and innovation. It will be a case study for building large public projects," says Abbie R. Goodman, executive director of ACEC/Massachusetts.

The legacy extends far beyond Boston. "Many of the design and engineering methods used for the Big Dig have been picked up and applied to other projects around the world," Bertoulin explains. And although some techniques are so specialized that they haven't yet made their way into mainstream engineering projects, the innovation and lessons learned have proved invaluable. "That's the nature of engineering and construction," Bertoulin says. "Every project draws on the knowledge gained from previous projects, and everyone benefits." ■

Samuel Greengard is a business and technology writer based in West Linn, Ore.