Bridging Borders in Scandinavia

by Peter Lundhus

High above the Flinte Channel off the coast of Sweden, the final 140-meter (459-foot) segment of the Øresund Bridge snapped into place this past August. After four years the 16-kilometer (9.9-mile) Øresund Bridge and Tunnel project—commonly known as the Øresund Fixed Link—is nearly finished. With the exception of the soaring twin concrete pylons that support the cable-stayed bridge, every massive, multiton part of the Fixed Link was cast or built elsewhere, floated out to the site and (like the colorful snap-together Lego blocks invented in nearby Denmark) assembled, piece by piece, on the spot.

The $3-billion Fixed Link is one of the largest infrastructure projects in European history. Its completion in mid-2000 will fulfill the age-old ambition of linking Denmark and Sweden across the Øresund Strait, by connecting the Danish capital of Copenhagen and the Swedish regional capital of Malmö.

The project entails three major structures: the world's longest underwater combined railway and motorway tunnel, more than four kilometers long; a 7.8-kilometer bridge with a cable-stayed section as its centerpiece; and an artificial island four kilometers long in the middle of the strait where the bridge and tunnel meet. Skillful prefabrication was the key to this project. It minimized the need for dangerous, difficult offshore work, made it possible to construct the bridge and tunnel parts in a controlled environment, and yielded a low rate of on-the-job accidents.

Continued on page 85

The Øresund Bridge and Tunnel will join Denmark and Sweden on July 1, 2000. Prefabrication of the project's complex components facilitated construction

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CONSTRUCTION OF ØRESUND BRIDGE
near Malmö, Sweden

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A SENSE OF SCALE: Workmen inside the tunnel are dwarfed by a steel bulkhead that seals one of the tunnel element's four large tubes designed for a railway or motorway.

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Continued from page 82

The tunnel segment of the Fixed Link, which stretches from the Danish coast to the artificial island (informally referred to as Peberholm), has five parallel tubes—two each for the railway and motorway, and a small tunnel that serves as an escape gallery. The tunnel consists of 20 prefabricated concrete elements; each element is made of eight separate sections. Workers at a specially built factory 12 kilometers north of the tunnel site cast the concrete sections indoors—each in a single 30-hour cycle—and then joined them together to form the tunnel elements. A single element is 176 meters long, 42 meters wide and nearly nine meters high; it weighs about 57,000 metric tons.

The ends of the completed tunnel elements were then sealed with huge steel bulkheads, and tugboats towed each assembly to the construction site. The final segment was positioned in the tunnel trench on January 6, 1999. On January 26, workers opened the bulkhead door between the last two elements, connecting Copenhagen on the Danish coast with Peberholm island.

For the bridge from Peberholm island to Malmö, the engineering team chose a cable-stayed design for the 1,092-meter center section. In this scheme the bridge deck is supported mainly by arrays of straight cables anchored directly to the vertical pylons—not carried by two or more main cables, as is the case with a traditional suspension bridge. This allows the freedom to design without the massive anchor blocks at the ends of the main cables yet still creates a very strong bridge that can accommodate the weight of the combined railway and motorway link. Notably, the Øresund bridge will carry the heaviest load of any cable-stayed bridge built to date.

Like the tunnel, the Øresund bridge was highly prefabricated. A factory on the east coast of Sweden produced the eight steel girders for the cable-stayed bridge. These girders were then transported by barge to Malmö for final assembly. The two approach bridges on either side of the high center span consist of 49 girders, each weighing some 6,000 metric tons. These segments were manufactured and assembled in Spain. Workers used the specially designed floating crane known as the *Svanen* ("Swan") to carry the bridge segments to the construction site and lower each one into place [*see top photograph on page 88*].

Construction of the Fixed Link involved a major dredging and reclamation effort of several million cubic meters of seabed material. The tunnel trench required the dredging of 2.2 million cubic meters of material. An additional 1.8 million cubic meters of seafloor was excavated during so-called compensation dredging, which repositioned and deepened the shipping routes of the Flinte and Drogden channels and also avoided blocking the movement of water, salt and dissolved oxygen through Øresund Strait to the Baltic Sea. Fortunately, the construction team was able to reuse all the dredged material from the ocean floor, primarily for creating the artificial island of Peberholm.

The Øresund Fixed Link will enable the 3.5 million inhabitants of the Copenhagen-Malmö area—whose commercial activities were limited by the lengthy ferry crossing of the strait—to develop this cross-border region into a major northern European center for business, transport, research and education.

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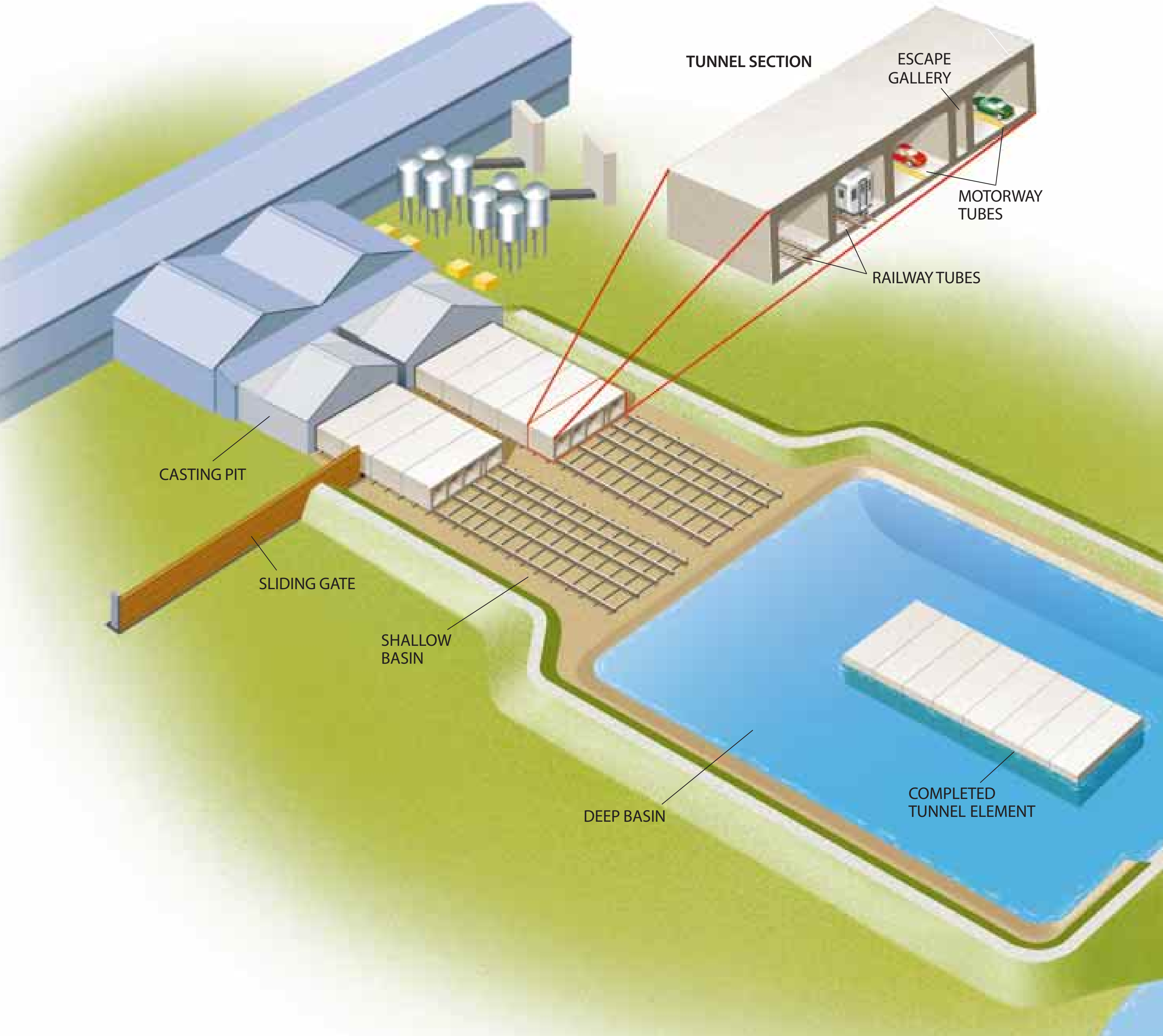

CASTING THE TUNNEL: At the factory north of the construction site, workers cast each 176-meter, 57,000-metric-ton tunnel element in eight individual 22-meter sections (*above*). As each section was joined to the next, hydraulic jacks pushed the lengthening element out of the casting pit and onto a ramp in a dry, shallow basin adjacent to a water-filled deep basin. Once all eight sections had been cast and linked to form one complete element, each of the element's five tunnel tubes were sealed with watertight steel bulkheads [*see photograph on preceding page*], creating a buoyant, air-filled concrete vessel. The sliding gate at the rear of the shallow basin was then closed and the basin was flooded with around 10 meters of water, until the tunnel element began to float. The element was pulled out into the deep basin and parked to await towing to the tunnel site. Workers then drained the shallow basin, making room for the next element.

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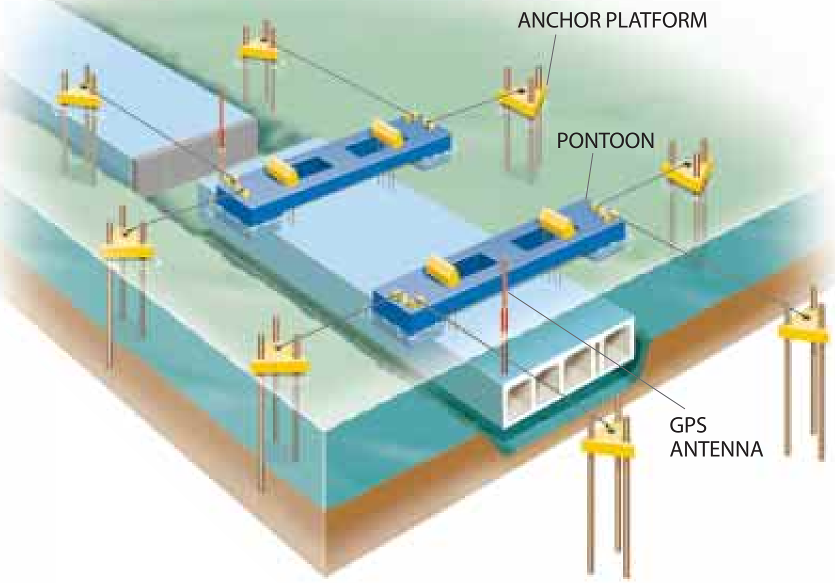
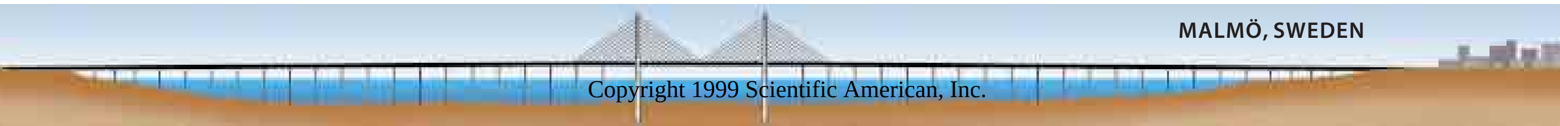


TOWING THE TUNNEL: Once one of the enormous tunnel elements—equipped with pontoons and floating almost completely immersed—had been moved to the deep basin, tugboats towed the piece to the tunnel site. When the element reached the site (*photograph above*), engineers positioned it above the tunnel trench and secured it to eight anchor platforms in the seabed (*above*). Next, they pumped water into the ballast tanks within the tunnel and lowered it into the trench. The final, precise positioning took place with the aid of the Global Positioning System (GPS), which allowed workers to position the element in the trench with an accuracy to within five centimeters. To connect the pieces of the tunnel, engineers pulled the newly immersed element against the previous one, where a set of rubber gaskets was installed between the two. As the two elements came together, a small reservoir of water was trapped between them. When the water was pumped out of the reservoir, the water pressure outside compressed the gaskets and sealed the joint. Workers then removed the giant steel bulkheads between the elements and ballasted the recent arrival with concrete so it would remain in place.

ILLUSTRATIONS BY GEORGE RETSECK



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BUILDING THE BRIDGE: The giant *Svanen* (“Swan”) crane places one of the final girders that make up the high center span of the bridge (*above*). Apart from the soaring main pylons, which were cast in place (two of them can be seen here with cranes attached to their tops), all other bridge components—the caissons, the pillar shafts of the approach bridge, the cable-stayed bridge girders—were lowered into place by the *Svanen* crane. Specially modified for the Øresund project, the *Svanen* has a maximum lifting capacity of 8,700 metric tons. The versatile crane can position the heaviest concrete and steel elements with the utmost precision, constructing the bridge much the way a child builds with a Lego kit. The upper concrete deck of the bridge carries the motorway, and the lower deck contains the railway tracks (*right*).

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ANCHORING THE BRIDGE: Pylons consisting of twin concrete towers support the cable-stayed bridge. These towers rise 204 meters above sea level, making them the tallest concrete structures in Sweden. The cables on the bridge follow the classical cable-stayed harp pattern and are anchored to the bridge girders of the 500-meter main span at 20-meter intervals and to the pylons every 12 meters (*below*). The foundations for the pylons and the approach bridge piers are 20,000-metric-ton prefabricated concrete caissons more than 20 meters high. Just as with so many other parts of the project, these pieces were cast in a dry dock in Malmö Harbor and then towed to the bridge site for installation below the waterline. The pylon legs were built on top of the caissons using climbing formwork and prefabricated reinforcing steel cages, visible on the tops of the incomplete set of towers at left in the photograph below.

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About the Author

PETER LUNDHUS has been technical director for the Øresund Fixed Link since its inception. In 1988 he joined the Great Belt company, which, in 1998, completed the Great Belt Link in Denmark, the predecessor to the Øresund Fixed Link. Lundhus received a master of science degree in civil engineering from the Technical University of Denmark in 1965.

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