A recent renovation project in Dresden, Germany sheds new light on the interior of the city's Main Station.

Shining Through

BY MIKE COOK

Adam Wilson/Buro Happold

IN THE UNITED STATES, IT IS COMMON TO TRAVEL LONG DISTANCES BY AIRPLANE. But in Europe, long distances are generally covered via train. So it is not surprising that one of the most urgent tasks for Germany, following its reunification, was the need to upgrade its national rail system.

Dresden Main Station, which was earmarked by the German national railway (Deutsche Bahn) for renovation in 1997, is one of the grandest pre-war train stations in Germany. It is also one of the country's busiest. Some 50,000 travelers pass through it on a daily basis on their way to urban, regional, and long-distance destinations.

Buro Happold helped execute the vision of London architectural firm Foster and Partners to replace the vast but gloomy spaces over the tracks with a soaring, translucent fabric roof that brings additional light into the station. To maintain the spirit of the original structure, Foster and Partners wanted to preserve the existing steel arches of the 1897 train halls.

A structural overhaul was necessary so that the new roof would not add excessive loads to the fragile supports, which had suffered damage at the end of World War II and inadequate repairs in subsequent years. To make the project work, Buro Happold collaborated closely with Foster and Partners and the local engineer in charge of the renovation, Schmitt Stumpf Frühauf und Partner.

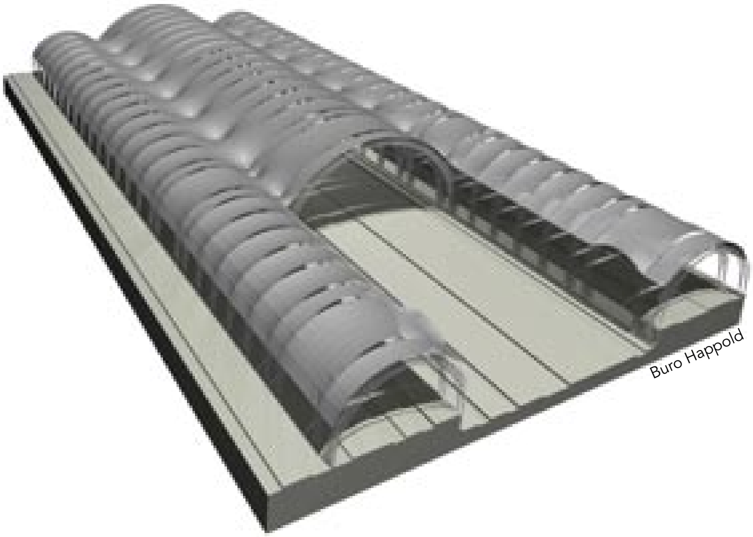
Structural Challenges

The station's footprint is 787 ft by 394 ft, which is divided into three parts: the entrance building and the middle hall (194 ft wide with a roof height of 98 ft) and two side halls. The north hall is 105 ft wide and contains four tracks, while the south hall has only three tracks and is slightly narrower. Both side halls rise to a height of 72 ft.

The existing roof cladding, a combination of corrugated metal and skylights, had been supported by steel arches with purlins spanning between them. The new 323,000-sq.-ft membrane roof imposed less weight, but the flexibility of the fabric material created horizontal forces on the steel arches, which were originally designed to carry only the vertical loads of the roof. The existing structure also had to transfer the loads of the fabric roof from the arches all the way down to the foundations.

Buro Happold helped to resolve these conditions through intensive studies in order to design and complete the installation of the roof. Major investigations were conducted during the design process to assess the strength of the steel and the existing structure of the station. These tests determined that the steel had significant structural weaknesses caused by years of poor maintenance and neglect—not to mention damage sustained by Allied bombing during World War II. In many places, it was corroded, deflected, and deformed.

To support the loads from the membrane roof, much of the steel had to be repaired or replaced, including entire bays of arches. Some of the existing foundations were also replaced and/or reinforced. In addition, the erection of the fabric roof



At the junctions of the arches, a special fabric configuration was required to collect and drain rainwater.

necessitated the use of a secondary steel framing system to sustain the new roof, as well as new roof lights, drainage pipes, and lightning protection.

Testing Assumptions

The sophistication of the new roof structure required that the team reconsider the entire structure of the station. The Buro Happold team began the design process by carrying out extensive calculations using Tensyl, its proprietary computer software. Tensyl has a three-dimensional interface that allows the firm to build and then analyze models to determine the information required for construction and installation. (Originally developed in 1978, Tensyl has since been used successfully by the company to design non-linear structures, such as fabric and cable-net, and assess how they will behave under a variety of load conditions.)

Another major challenge the team faced was the choice of a translucent fabric for the roof, that was not fully approved as a building material—particularly for train stations—because of its potential fire hazard. During the planning process, several possible membrane fabrics were considered. The team decided on a Teflon-coated glass fiber fabric over PVC-coated polyester because of its strong resistance to fire, diesel fumes, and staining, as well as its self-cleaning properties.

Buro Happold investigated the ways fabric could be stressed between the existing steel arches, while identifying the problem zones, such as those with high tension stresses or excessive deflections. The total roof area was divided into nine different bay types in order to test all relevant load cases and load case combinations. This analysis allowed the design team to develop the shape of the membrane and its points of connection to the existing structure.

The fabric structure and the design assumptions were also tested in relation to the existing structural arches, since the original steel was old and damaged and therefore much less ductile than a contemporary material. The design had to account for such things as temperature changes and the failure of the membrane panels in the event of an unexpected catastrophe or the impact of point loads (from maintenance personnel, for example). Any of one of these conditions alone could disrupt the integrity of the structure and the strength of the roof.

Raising the Roof

After reviewing many different options during the design phase, Buro Happold developed a structural solution that added a secondary, triangulated steel structure directly on top of the existing steel arches. To prevent further damage to the existing steel due to welding, the two structures were bolted together for stability.

The fabric membrane was lifted 3 to 6 ft above the main arches, based on a study of the forces on the fabric structure, then fixed to the secondary steel framing system. Transfer loads from the membrane were then passed from the secondary structure to the top chords of the old steel arches.

To make the fabric roof structure resistant to wind and snow loads, the design team developed a double-curved fabric form that created the required stiffness to span the maximum distances between arches, up to 46 ft. The team linked pairs of arches in the secondary structure with rigid purlins that act as lateral trusses, to provide additional stiffness. This design avoided the need for secondary purlins, which were present in the previous roof structure. The spaces in between the paired arches were linked only by the fabric, so that the whole structure would flex to accommodate the elongation that normally occurs in steel when temperatures change.

Since the fragile arches had little resistance to horizontal forces, the longitudinal loads of the roof were transferred to the end bays of the station. The bays were then braced, turning them into 33-ft-wide trusses. To prevent catastrophic failure of the membrane, additional horizontal cables were inserted underneath the fabric to support the membrane, if needed, under extreme load cases.

Creating new Connections

Although the fabric membrane was much less expensive and lighter than glass, the roofing material made necessary the design of a customized solution for linear membrane clamps to attach the fabric roof to the secondary steel structure via steel plates. This detail had to work with the membrane roof and the top chord of the secondary structure, yet remain cost-effective to install and produce.

Whereas the steel plates that connect the fabric to the secondary steel structure were fixed, the clamps themselves had to accommodate for movement of the membrane structure. Once a clamp was installed and stressed, there were no further methods available to adjust the membrane tension. This meant that the fabrication had to be extremely accurate.

Each bay had to be modeled individually, using the computer model to determine the angle of the clamps at each point of connection. The team supplied this three-dimensional information to the steel fabricator for inclusion on their shop drawings.

Since the clamps and the fabric materials had never been used before by Deutsche Bahn, the team had to obtain approval for their use. Buro Happold submitted all structural calculations and drawings, as well as material tests that described the behavior of the material and structure. This involved laboratory testing of the fabric to verify the long-term characteristics of the material, including flex tests to demonstrate the durability of the clamped fabric edges under repeated load cycles.

From Darkness to Light

Dresden Main Station's official reopening in November 2006 coincided with the 800th anniversary of the founding of Dresden. Today, the station that was once so dark and neglected is now bathed in natural light. Within the halls, the membrane roof appears to float over the 19th-century steel arches. From above, the fabric creates a gently undulating impression in Dresden's cityscape, an indication of how the city is rapidly moving forward into the 21st century. MSC

Mike Cook is a partner with Buro Happold.

Rudi Meisel/Foster and Partners

Stretched between the existing steel arches (circa 1897), the translucent fabric brings daylight into the main train shed.

Owner
Deutsche Bahn Station & Service AG
Regionalbüro für Großprojekte
Dresden

Architect
Foster and Partners, London

Planner and Structural Engineer
Schmitt Stumpf Frühauf und Partner

Structural Engineer (Membrane Roof)
Buro Happold

Project Manager
Homola AYH AG

General Contractor
ARGE Dywidag und Heitkamp