GRAND INSPIRATION

Heavily damaged during World War II bombing raids, the main railway station in Dresden has been refurbished by a team of British and German architects and engineers. The 30,000 m² prestressed membrane roof that is significantly lighter than its predecessor. But the horizontal forces imposed by the new roof presented formidable design challenges.

By Robert L. Reid

A team of British and German architects and engineers restored much of the station in Dresden has been refurbished by a team of British and German architects and engineers. The centerpiece of the station is a 30,000 m² prestressed membrane roof that is significantly lighter than its predecessor. But the horizontal forces imposed by the new roof presented formidable design challenges.
When Allied bombing raids in February, March, and April 1945 targeted th
Germany, the fires and pressure waves created by several thousand tons of explosive ordnance caused considerable damage to the Dresden Hauptbahnh station, once ranked among the most impressive transportation structures in major buildings in the historic city, the station was not destroyed in these at
After the war Dresden fell under the control of the communist German Den German initials)—also known as East Germany. Poorly implemented repair during slightly more than four decades of DDR rule led to further damage a appearance. Of greater significance, corrosion and weather-related damage of the steel arch structure, notes Peter Voland, the head of the structural eng Stumpf Fruehauf & Partner (SSF), of Munich, Germany, the lead engineerii €140-million (U.S.$192-million) refurbishment of the station.

The refurbishment was designed by the London-based architecture firm Fos Architecture Prize–winning Norman Foster. The project restored much of tl Wilhelmine-style grandeur, strengthened the structure’s arches and other su restoring a glass cupola, and added a distinctly modern touch over the three translucent prestressed membrane roof designed by the London and Berlin (engineering firm Buro Happold. The initial planning for the project began in itations, and was completed in November 2006—in time to help commemo founding of Dresden.

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The membrane roof, above, is divided into a series of fabric panels that range in width from 5 to 14 m—determined by the basis of the spacing between arches. The roof’s geometry follows a double curvature of high and low points that alternate between ridges, where the membrane rises above the arches, and valleys—called pull-downs by the design team—formed where the roof of the middle hall intersects with the roofs of the side halls. Tensioned cables stretch across the halls in a north–south direction, lifting up the membrane to help generate the form of the roof canopy. Unstressed cables hang loosely beneath the membrane panels to help maintain the stability and continuity of the roof in the event that any panel fails catastrophically or needs to be removed for maintenance or repair. The western facade of the masonry reception building, right, opens onto the middle platform hall, which features filigreed steel arches
that rise to a height of 32 m. In every second arch bay, a portion of the new prestressed membrane roof is pulled down to form a conical hopper that collects and drains rainwater from the roof into pipes located inside the arch columns. To accommodate the membrane roof’s horizontal loads of 500 to 600 kg/m—which snow and wind could increase to 1,500 to 2,000 kg/m—the design team added a secondary steel structure atop the arches; the membrane connects directly to this secondary structure, not to the arches.

The station remained open during all demolition and construction work but August 2002, when, as part of widespread flooding throughout central Europe, the Weisseritz, which had been diverted in the 19th century so that the station could return to its original riverbed through the middle hall, notes Voland. Beam was conducted atop elevated, movable platforms that provided workers with of the arches, the restoration itself was only slightly delayed by the flooding.

A critical success, the refurbishment of the station received the 2007 European Prize of British Architects (RIBA) and is one of six finalists for this year’s £20,000 prize by the RIBA and the Architects’ Journal to the architects deemed to have made British architecture in the past year. The winner of the prize will be announced also one of three finalists for the Institution of Structural Engineers’ Heritage Award which will be announced on November 14.

Constructed between 1892 and 1897 at the southern border of Dresden’s do of three arched ingot-iron platform halls—designated the north, middle, and the eastern facade of an approximately 4,500 m² masonry reception building Giese and Paul Weidner, it was considered one of the grandest railway stations I, notes Voland. The reception building featured a 34 m high glazed square addition to steel filigrees on the arches in the platform halls, there were large vaulted ceilings above the platforms, cast-iron ornamentation throughout th
facades on the longitudinal exteriors of the north and south halls that feature portals with steel mullions.

The north and south halls each measure approximately 240 m long. The north hall has a width of 32 m, and their steel arches rise to a height of 19 m. The south hall is 59 m wide—and its main arches rise to a height of 32 m. The standard arches spaced at 10 m intervals, but the arches framing the main entrance to the platforms halls—just behind and on either side of the reception building—are set 14 m wide bays. Several 8.5 m wide bays and additional 5 m wide bays are located on the south halls that extend along the sides of the reception building.

Before the current refurbishment, the station had undergone various alteration. Cast-iron components were replaced by brick masonry, for example, and the original corrugated metal roof was covered by timber and felt after World War I. Platforms halls into dark caverns. Thus, a first step in the refurbishment involved the existing structure to demarcate the original construction and any additions or original structural designs could be found, the refurbishment team was rebuilding and to conduct a detailed condition survey of the structure, including Voland.

Foster’s vision for the project included the removal of components that were possible, the repair of the original components. “The aim of the refurbishment is to restore the former glory as a light, airy space and to avoid new structures,” says Voland. Determined that the entire steel arch structure, the main structure of the glazed steel-mullioned gable ends of the three platform halls—known as the Halle Arch—were tied back on top of masonry piers and in the interior masonry faces of the structure. Although the tension was superimposed by the weight of the pillars, notes Voland, the steel structure itself, as well as the timber, glass, and metal sheeting on the arches were damaged by corrosion and had to be demolished and replaced. The cast-iron columns were always possible to access the rear portions of these steel elements and the mullions of various supports that were constructed of either natural stone or masonry piers and in the interior masonry faces of the structure.

Because the columns of the middle hall arches were located directly in front of the station’s arches were originally designed primarily to transfer the vertical loads to the foundations. But it was not an easy process.
corrosion protection. The solution required the use of hydraulic presses to lift columns were then cut and removed for restoration off-site. Where new corrosion protection was not required, the steel members were first covered with dust-resistant metal sheets so existing lead-based protection would not create an environmental hazard. A new corrosion protection consisting of a two-component epoxy coating was applied, says Voland.

The centerpiece of the refurbishment was the addition of a 30,000 m² prestressed thin glass fiber translucent canopy is coated with polytetrafluoroethylene (PTFE), similar to the 320 m diameter roof of London’s Millennium Dome (see “Falling in Love with the Dome,” Civil Engineering, May 1999). Although the new roof is considerably heavier than previous covering—approximately 1.2 kg/m² for the membrane roof, compared to 1.0 kg/m² for the postwar roof—the membrane system imposed considerable horizontal forces on the structural supports that previously had accommodated primarily vertical loads. These horizontal forces could increase these horizontal forces to 1,500 to 2,000 kg/m, he adds.

Thus, to support the new roof, the refurbishment featured a conversion of the arch structural system. All of the existing purlins were removed and in their place new steel pipe purlins and cross bracing—was added to every second bay to create 10 bays between these arches. In this way the loadings of the membrane’s longitudinal forces on the end bays—where wind loads can be significant—were distributed across the 10 bays, the project also strengthened the main vertical portals of the gable enclosures.

The €140-million (U.S. $192-million) refurbishment project repaired the masonry and natural stone features of the approximately 4,500 m² reception building, created new space for shops to line the building’s cruciform arcades, restored a 34 m high glass cupola, and installed a movable transparent foil cushion in the cupola to facilitate natural ventilation. Designed by the Pritzker Architecture Prize–winning British architect Norman Foster, the station refurbishment has already received one architecture award and is a finalist for another architecture prize as well as a structural engineering award.

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bracing, installing additional bracing, and adding reinforced-concrete panels.

Michael Cook, Ph.D., CEng, Buro Happold’s London-based director of structural engineering, says horizontal tension in the membrane roof to the pull on the edge of a trampoline is a very challenging aspect of the project,” says Cook. “A normal

The refurbishment team initially questioned how much resistance the existing structure, whether they would be flexible enough to accommodate potential loads, says Cook. To ensure that the membrane flexed as required, the team designed a secondary structure to sit atop the arches; the membrane is connected directly to the secondary structure, explains Cook. Vertical and horizontal loads are transferred from the arches through this secondary structure, which consists of pairs of tubular pipes in diameter with 8 mm thick walls. Balanced longitudinal stresses and the horizontal forces transferred to all arch bays at either end of the platform halls. These end with additional cross bracing to provide horizontal stiffness; the additional cross bracing was designed to mimic the station’s original bracing.

“Later on, it turned out that the arches were actually laterally very soft and we imagined they would,” Cook says. This enabled Buro Happold to stiffen the entire structure separating the membrane and the arches was still useful because it allowed light,” he adds.

The membrane itself transmits approximately 13 percent of daylight, significantly artificial lighting inside the platform halls. Of greater importance, the use of the membrane sufficiently provide space for a series of skylights which would have been attached directly to the simple steel boxes of the arches. These skylights—which would have been attached directly to the simple steel boxes of the arches—glimpse of the sky,” notes Cook. Moreover, artificial lighting from the platf of the canopy at night, “creating an even wash of illumination, while from the skylights in the north and south halls. These flying cables lift up the membrane and help generate the form of the roof canopy. “It’s that lifting and pulling of the membrane that gives you the tension” for the roof geometry, explains Cook.

The tension of the flying cables also generates significant additional horizontal forces, says Voland.

A second set of tensioned cables—outlining the openings at the top of the membrane—transfer the snow loads that fall on the membrane roof. Although Dresden is winters, whatever snow does fall will drift into the hoppers, building up con

Divided into a series of fabric panels that range in width from 5 to 14 m—d spacing between arches—the roof’s geometry follows a double curvature of where the membrane rises above the arches and helps form valleys—called pull formed where the roof of the middle hall meets the roofs of the side halls. It down points form a conical hopper that collects and drains rainwater from the arch columns. The double tubes of the secondary supports connect to the pipe rings.

In the bays without hoppers, a series of highly tensioned cables—called flyi in a north–south direction, connecting the ends of the glazed skylights in the skylights in the north and south halls. These flying cables lift up the memb help generate the form of the roof canopy. “It’s that lifting and pulling of th gives you the tension” for the roof geometry, explains Cook.

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high stresses on the membrane, says Cook. The snow cables strengthen the arch to another by a contoured diversion around the top of the hoppers to tri arches.

A third set of cables hangs loosely between the arches and beneath the membrane at either end of each platform hall. Although this untensioned system of roof structure under normal conditions, the cables act as a replacement “ski to maintain the stability and continuity of the membrane in the event that any catastrophe or needs to be removed for maintenance or repair, explains along the longitudinal facades of the side halls, the membrane is fixed cont. The latter follows the curve above the 14 m wide entrance portals and is restraint steel tube arch, notes Voland.

To erect the new roof, the membrane panels were stretched into position using then bolted to the secondary steel supports via small metal plates that had been formed within two tubes. Each plate had to be welded at a precise angle to maintain the stability and continuity of the membrane in the event that any catastrophic event needs to be removed for maintenance or repair. But the refurbishment team chose to use the fabric’s manufacturer—Skyspan (Europe) GmbH, of Rimsting, German sufficiently to be pretensioned into position.

Buro Happold worked closely with SSF to design the membrane roof throughout form finding, and computer analysis using a proprietary software system of Erection of the membrane roof began in February 2001 with the removal of temporary supports were required during the erection of the membrane and prevent excessive loading on the arches, notes Cook. Once the membrane was tensioned, the temporary struts were removed.

From an aesthetic standpoint, the membrane roof opens up an impressive view of the hard roof used to come all the way down around the arches, down in the valley line, notes Cook. “So within the station you could see only the shape of other arches were rendered invisible by the valley line, which was very low to provide light but also raises the valleys higher.”

This created an arch-based pattern in the lengthwise direction, explains Cook. Station now you not only can appreciate the nearest arch but looking through the whole roofscape together,” he explains.

On the longitudinal facades of the platform halls, the refurbishment team removed bricks that had been used after World War II to cover damage to the sandstone columns left intact by Voland. During the refurbishment, the Deutsche Bahn design office also designed the cupola located directly above the 70 m long central concourse. The cupola’s original glazing—covered by the post-WWII era—was replaced with a new, movable transparent foil cushion was installed beneath the cupola to reflect light.
movable foil seals in the heat during cold weather and permits hot air to escape.

The original waiting rooms in the reception building have been converted to office area, and space has been created for shops to line the concourses.

As part of the refurbishment, the station will now serve Germany’s InterCity ICE trains, which are much longer than the trains that previously used the station. In each case, a team considered extending the membrane roof by as much as 200 m beyond the existing arches—to accommodate the ice trains—with some “amazing geometries and free of the restraints imposed by the existing arches, notes Cook. But finance those plans for now, notes Voland.

Perhaps the greatest challenge during the project involved integrating modes important features of the 19th-century structure, notes Voland. The new roof was not to rest comfortably on the original station arches—revealing the fine historic space below with natural light, reducing energy consumption, and reinventing the century.”

Project Credits
Owner: Deutsche Bahn AG Station & Service
Architect: Foster + Partners, London
General planner and structural engineer: Schmitt Stumpf Fruehauf & Pa
Structural engineer for the membrane roof: Buro Happold, London and
Project managers: AYH Homola GmbH & Co. KG, Dresden, Germany (reception build
Baucontrol Ingenieurgesellschaft mbH, Dresden, Germany (reception build
General contractor: ARGE Dywidag und Heitkamp, Dresden, Germany
Subcontractor for membrane roof: Skyspan (Europe) GmbH, Rimsting, Germany
Mechanical and electrical engineers: Schmidt Reuter & Partner, Dresden, Germany
Zibell Willner & Partner, Dresden, Germany, Ingenieurbüro Steinigk, Cottbus
Kompetenzzentrum Gebäudeautomation Krause, Erfurt, Germany (reception build
Engineering review: Prof. Ruehle, Jentzsch & Partner GmbH, Dresden, Germany

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