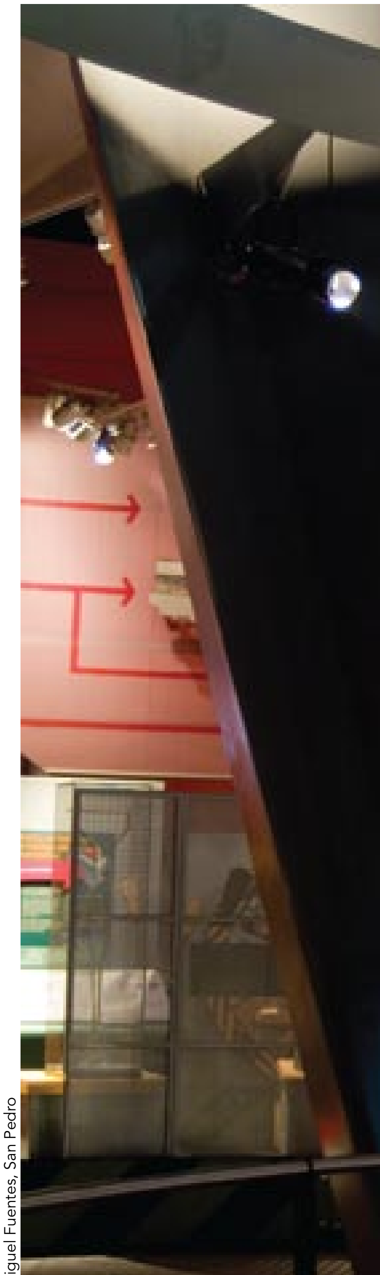
From Mill to

Miguel Fuentes, San Pedro



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A former Mexican steel mill lives on as a museum, invoking the past, present, and future of the material.

THERE ARE SOME PLACES WHERE THE PAST LINGERS. And that can be a good thing.

At Parque Fundidora in Monterrey, Mexico, the area's industrial past is apparent. Part of the site, a defunct steel mill, was turned into a steel museum, and the remaining blast furnace leaves no question as to the building's original use. The Museo del Acero (Steel Museum) opened to the public last fall and was immediately designated a Monumento Nacional de Mexico.

A portion of the museum complex is the old steel mill that was refurbished and made accessible by open-air walkways. A new building is connected to the existing structure at ground level; due to the site's topography, the new building is partially located underground.

Two structural elements are particularly noteworthy when looking at the new building: the faceted roof of the Steel Gallery and a "floating" helical staircase.

Multi-faceted

The Steel Gallery is an underground exhibition space demonstrating the structural potential of steel. The roof covering the Steel Gallery is itself also a demonstration of this potential. The roof is constructed of relatively thin steel plates (maximum thickness is approximately 0.5 in.) with a maximum span of about 42.5 ft and a total diameter of about 98 ft. Seen from above, the steel plates span from an outside circle made of concrete walls to an inner circle of 12 angular steel columns. The bottom of each column is triangular-shaped. At the top, there are two triangles side by side in plan, meaning that from every corner at the top, two edges run towards one corner at the bottom. Finally, the complete column consists of six triangular-shaped plates; together, they form a "chevron." Above the inner circle of columns is composite construction carrying a terrace and a small bridge connecting the terrace to the main building.

In order to avoid local buckling, multiple folds were introduced into the roof geometry. These folds allow for a variation of the structural height, depending on the span of the steel planes and the moment distribution. This helps to minimize stresses due to vertical loading; additional beams or stiffeners were not required. Finally, the originally designed plate thicknesses were adapted to market availability in Mexico.

The columns of the inner circle have a unique shape. They support the roof by deforming their top plates into the folded roof elements, hence forming a rigid moment connection at the top. In addition, the columns have chevron-shaped horizontal cantilevers at their top; these cantilevers support the terrace structure above. At their bases, the columns are hinged to the concrete floor.

Welded plate steel columns are supported on adjustable triangular base plates flush with the finished floor level. The base plates rest on concrete pedestals, with the roof drainage integrated into

Above, left: Parque Fundidora is the setting for the old steel mill and the new museum building.

Above, right: Triangular chevron-shaped steel columns in the Steel Gallery.

Museum

BY WERNER SOBEK, ANGELIKA SCHMID, AND FRANK HEINLEIN

the columns. The tapered and cantilevering central terrace supports provide sliding layers to allow for horizontal movement of the terrace above, and thus avoid restraining the steel roof structure. In the horizontal direction, the terrace is supported by the bridge linking the terrace to the main museum building. Thus, the architectural idea of tapered triangular steel elements is converted into a structural system suitable to support both the roof and the terrace.

A 3D finite element model employing iso-parametric shell elements (RFEM by DLUBAL) was used to model the roof and the columns of the Steel Gallery. Even for thin steel plates (between 0.4 in. and 0.5 in. thick), the maximum deflection due to dead load is less than 1.14 in. When using the most critical ultimate limit state factored load combinations, stresses in all steel plates (material grade A572 Grade 50) remain within allowable limits. Stability checks were performed using second-order nonlinear analysis. To ensure that plates remain stable under compression, additional hand calculations were performed for individual plates, using plate buckling theory.

It was also shown that under an accidental load case situation (with reduced partial safety factors), the steel roof remains stable, even if one column fails entirely. This high safety potential results from the possibility of plastic load-redistribution.

In order to minimize welding on-site and to optimize quality, larger steel pieces were shop-welded, inspected, and then

Right: The roof of the Steel Gallery.

Below: Helical stair with cantilevered threads and pre-stressed cables.

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transported to the site. After installation of the columns as well as the outer ring walls, large segments of the roof were lifted into place and then site-welded into a monolithic folded surface.

Ascending the Helix

The two levels of the new museum building are linked by an elevator and a flight of stairs winding around it. The steel columns arranged in a circle around the elevator support the elevator structure as well as the roof structure above. This roof structure cantilevers outwards from the columns to the façade edge beams and therefore spans over the stair structure. From those edge beams, thin cables are pre-stressed against the ground, holding up the handrail profile, which thus seems to "float" around the staircase without any uprights. The staircase stringer and treads are made of welded triangular steel plates; welds are ground flush for aesthetic appearance with clear geometry lines and sharp corners. The cantilevering treads are only supported by the stringer without touching the outer handrail cables. The custom-made stringer profile is helical and spans from a triangular base plate at the concrete floor (moment connection) to the top steel beams of the composite landing slab (also moment connection).

In order to minimize possible resonance problems, the stair was designed for a sufficiently high relevant natural frequency ($f_{1,\ staircase}$ = 2.7 Hz). The stringer support is a rigid moment connection where support forces and moments are anchored into the ground. At the junction of stair tread, stringer, and triangular base plate, shear studs and concrete anchors develop sufficient lever arm to transfer forces to the concrete floor slab. In case of any unexpected vibrations during use (especially combined horizontal/twist modes), the inner stringer can easily be connected locally to the outer elevator shaft columns.

Like the Steel Gallery's roof, the elevator structure and the helical stair were modeled by means of a 3D finite element calculation (RSTAB by DLUBAL). Member sizes were chosen to keep stresses and deflections within clearly defined limits. The pre-camber of the staircase treads was also determined according to finite element modeling. As steel structures offer relatively little damping, the first natural frequency of the system was raised high enough so as to minimize the risk of resonance due to walking. On-site frequency measurements were carried out to check the staircase behavior under walking conditions. These measurements confirmed the correctness of the previous assumptions.

The staircase was pre-fabricated off-site using temporary scaffolding and then lifted onto a truck for transportation to the site. The final lift on-site was performed using a mobile crane. Anticipated deflections due to dead loading were pre-cambered and also compensated by using wedge-shaped shimming plates below the triangular base plate of the stringer profile. Thus it could be ensured that treads were in a perfectly horizontal position after erection.

Living History

For both the folded roof of the Steel Gallery and the helical staircase, the potential of steel was used to the fullest extent with regard to material strength, structural design approach, and construction technology. And this potential is invoked in a unique way—in a facility that used to produce steel and now not only teaches visitors about the history of the material, but also incorporates it in innovative ways.

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