SPAN

Innovation in Architectural Steel

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How to span

- Beams (wide flange, box)
- Planar trusses
- Box trusses (straight span or arch)
- Arches
- Suspended systems
  - Suspend a platform/floor from an arch
  - Suspend a platform/floor from a mast

Why are you making the span?

- Is it a bridge?
- Will there be moving loads on the span
- Is it a floor area that you desire to be column-free
- Why do you not want columns?
- Is it a large roof covering that needs to be column-free?

One way or Two way?

- Is there a dominant span direction?
- Bridges are directional and usually have a primary span across with some secondary elements to create the width
- Linear buildings have a dominant span direction usually across the short dimension
- Wide buildings need to select a span direction, but structure goes 2 ways

Performance issues

- Bending strength
- Limits on deflection
- Limits on vibration
- Need to drain surface (roofs and bridges)
- How does the length of span relate to transportation and fabrication?
- Lateral stability (sway or kick-out)

Owner
University of Toronto, Scarborough Campus

Architects
NORR Architects

Construction Manager
PCL

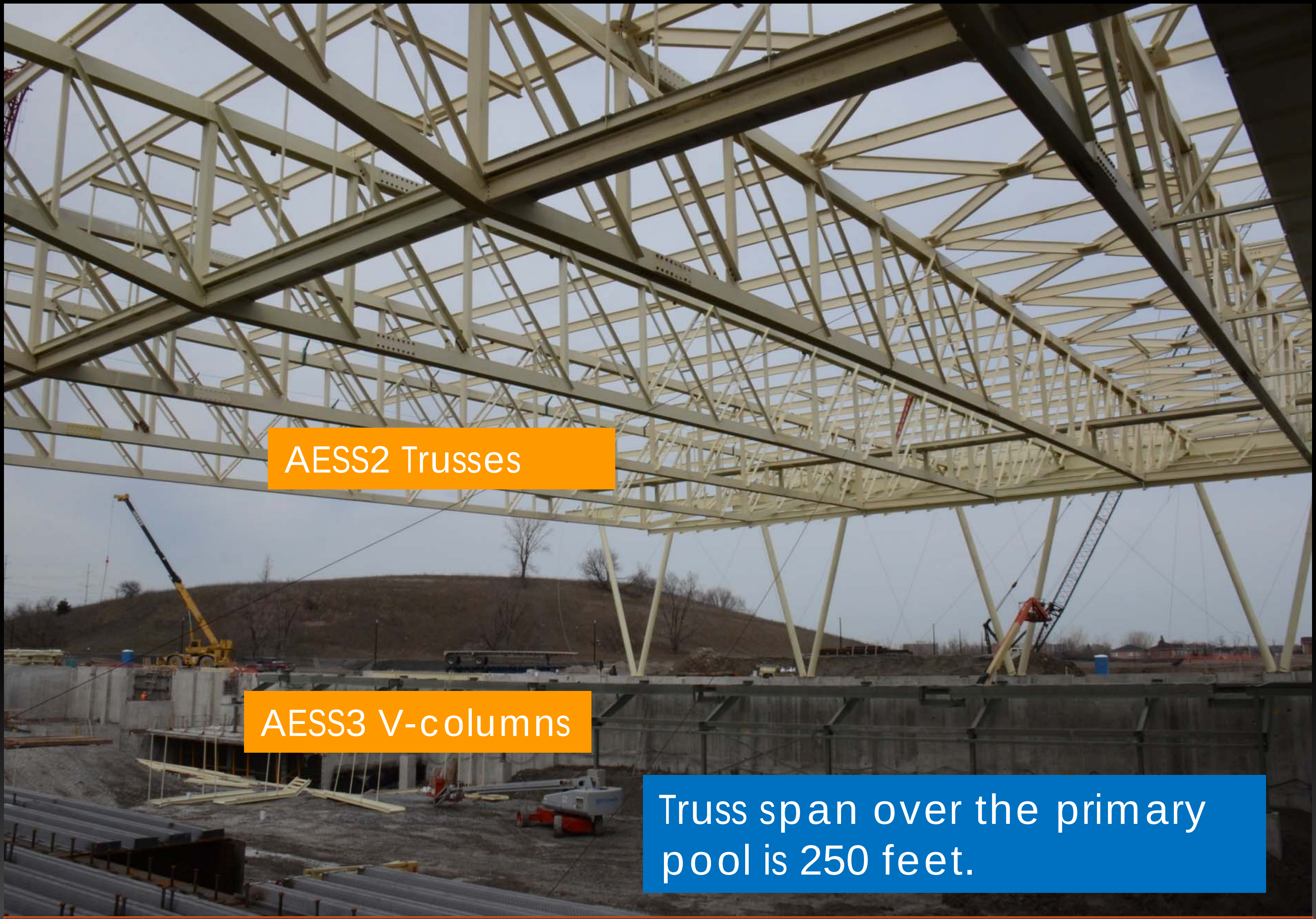
Structural Engineer
Yolles

Steel Fabricator / Detailer / Erector
Walters Inc., Benson Steel, Casey Welding

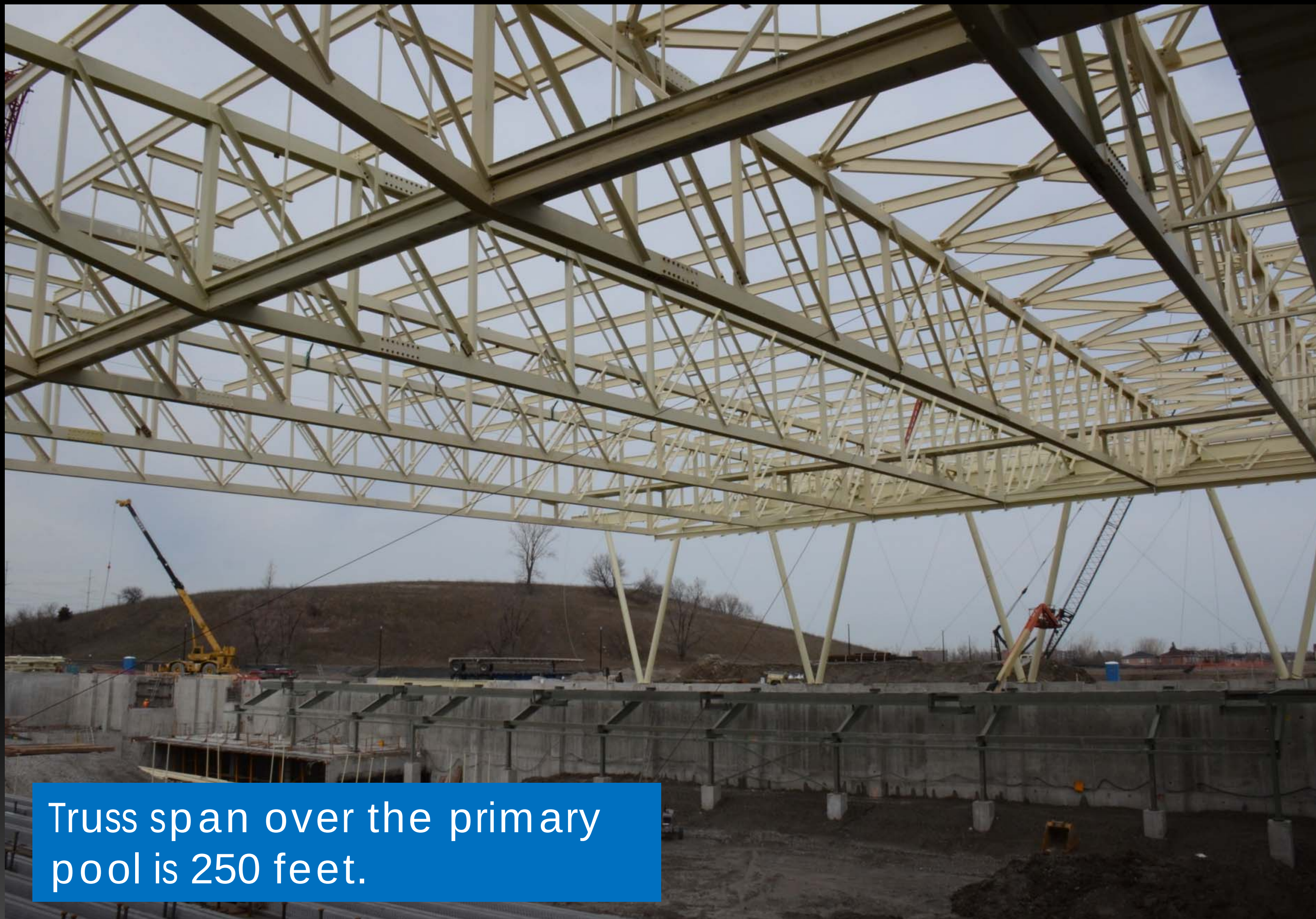
AQUATIC CENTRE FOR THE 2015 PANAM GAMES
Toronto, Ontario

Taking the steel design from the rendering, through AESS Category consideration and to reality requires the input of the fabricator.

Working with the fabricator



AESS 2 and 3 Combination 2



Details of the trusses

Different categories of AESS are chosen in combination with standard structural steel for concealed work.

Differentiated steel throughout

Although the overhang will be clad, the concealed steel is primed as not to stain the AESS during construction.

Primed steel

The Y columns are AESS3 and the trusses are AESS2 as they are well beyond the 6m viewing distance.

Different categories


Column to beam connection

Ladder design of web members

Bolted vs welded connections

Splicing the trusses

Discreet locations for bolts saves from site welding.

Site sub assembly allows for the delivery of materials that fit on transport trucks but lifting larger members.

Close up of bolted splice.

This smaller roof is simple AESS1.

Training pool roof is simpler

TRUSS BRIDGES

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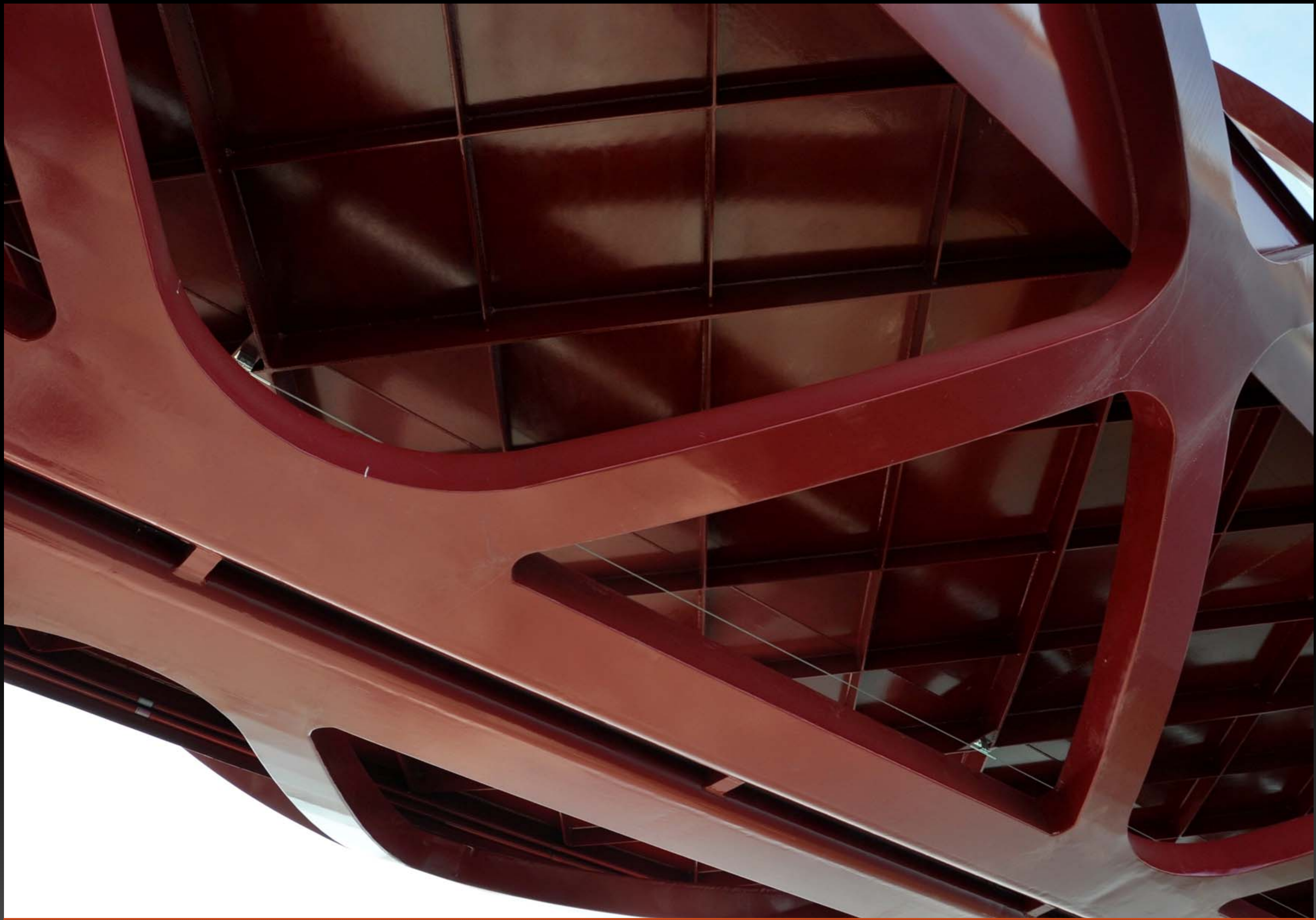
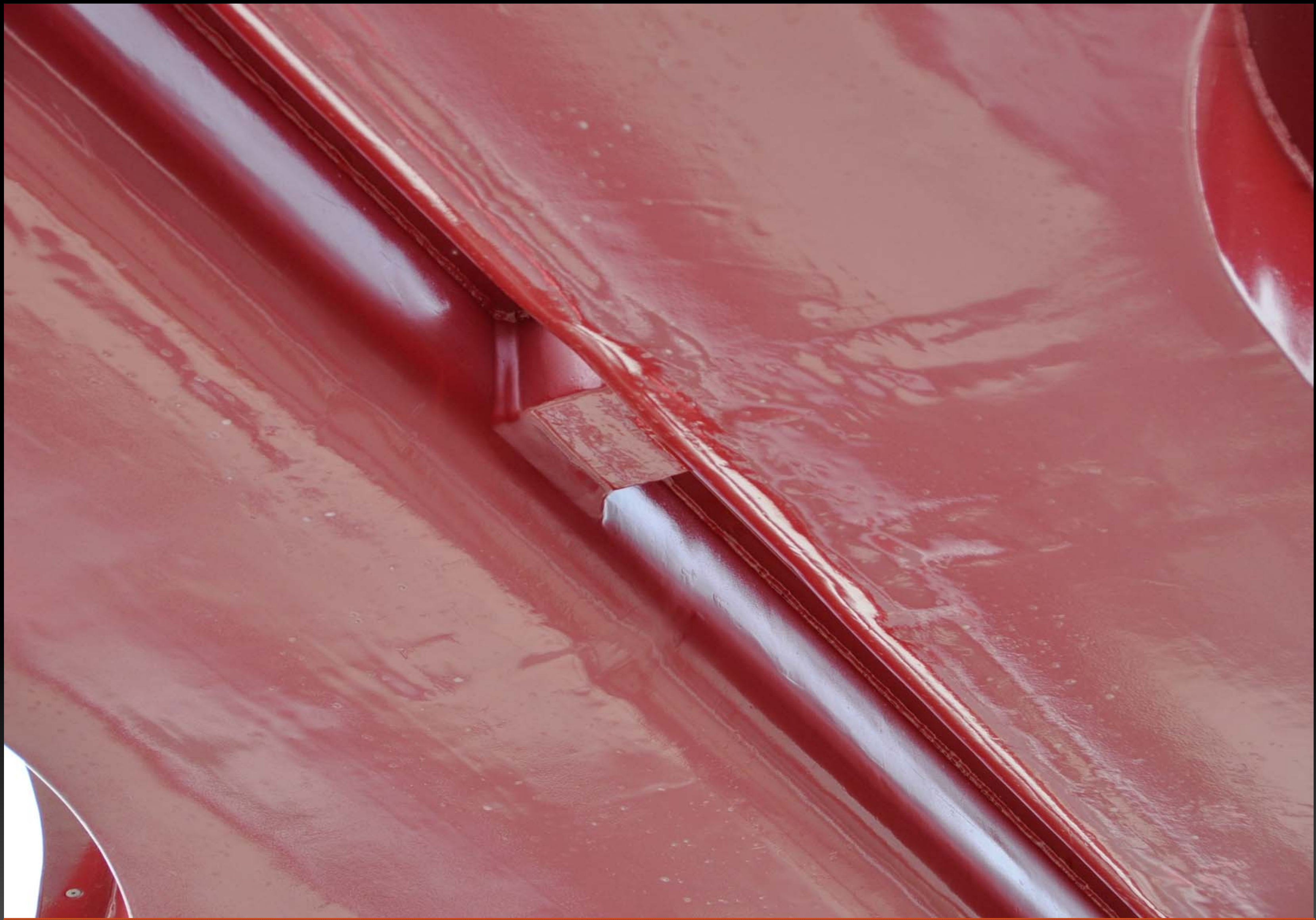
The new Peace Bridge in Calgary, designed by Santiago Calatrava, uses a diagrid type of "Chinese Finger Tube", in a fully welded scenario, to create a very slender span across the Bow River. Span 130 m.

The end of the tube has been substantially thickened to provide support at the end. The bridge is created from sections of bent plate with internal reinforcement.



The floor has been built into the tube (constructed first). Plate steel ribs have been welded to a plate steel floor to provide reinforcement. The bottom of the bridge shows the small HSS stubs that have been welded into the diagrid halves.

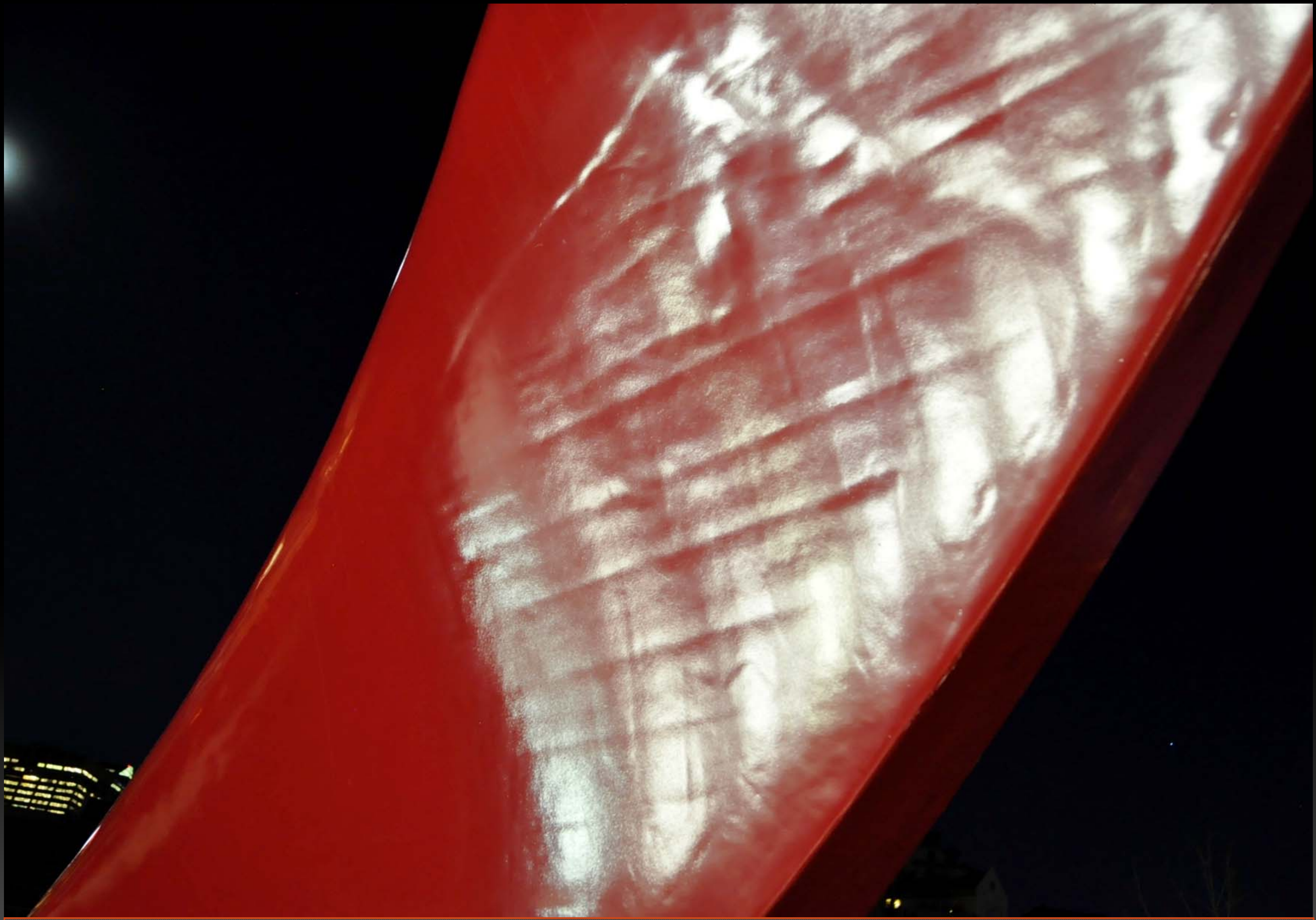
The smooth finish of this AESS4 structure, in combination with the large open panels and translucent glazed panels, give a light and airy feeling to the bridge interior. The interior was to have been painted white.



Very small traces of show through weld are visible, indicating where the internal reinforcements are positioned. The rounded edges of the final product would have made the proposed white painted interior rather impossible to achieve.

Night lighting can be strategic, but it will have impact on the requirement of the forming and finishing of high level AESS work.

At night the up lighting illuminates the interior of the bridge, highlighting surfaces that are not lit during the day. The evidence of the brake forming shows through quite clearly.



A note of caution when choosing both a forming method and a finish. Night lighting can highlight imperfections in the steel that are not evident with regular day lighting. Here the lines of the brake forming translate through the finish.

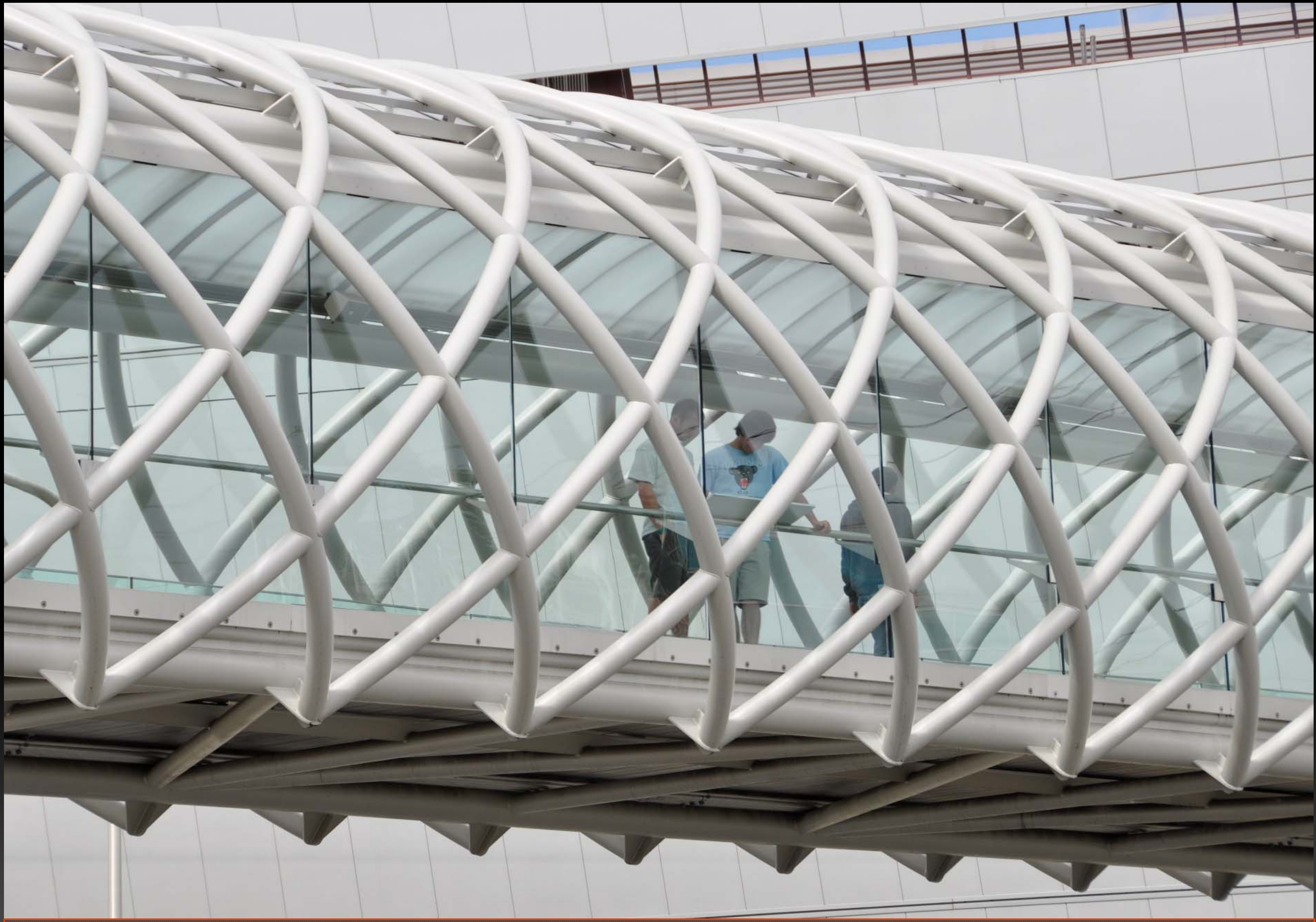
The member differentiation and use of tensile members has been done in this case to raise the interest level of what could be a dull pedestrian overpass over the rail tracks into something a little bit more interesting.

Part of the function of the tensile members along the side of the bridge is as a deterrent to jumpers.

Many innovative AESS projects make use of a combination of curved members with tension systems. Here bolting is used to simplify site erection. Stainless bolts are used for contrast with the paint and a higher level of durability.

Although some of the tensile members act to stabilize the bridge, much has been done simply to make the structure more fun.

Seattle Museum of Flight



There is a dominant direction to the complete tubes with X members welded into.

Think about how the steel was curved and welded. Even lattice with a hidden direction.

Interior view down the bridge. Slight arch as it passes over the roadway.

Underside of bridge is a fairly simple planar truss, with the tubular section welded to at the sides.

Pedestrian bridge outside of Vancouver. Box truss gently arched as it passes over the street.

Underside of bridge must support a secondary structural system that comprises the walkway.

View of secondary spanning systems. Note bolted connections at connection to top part of bridge truss.

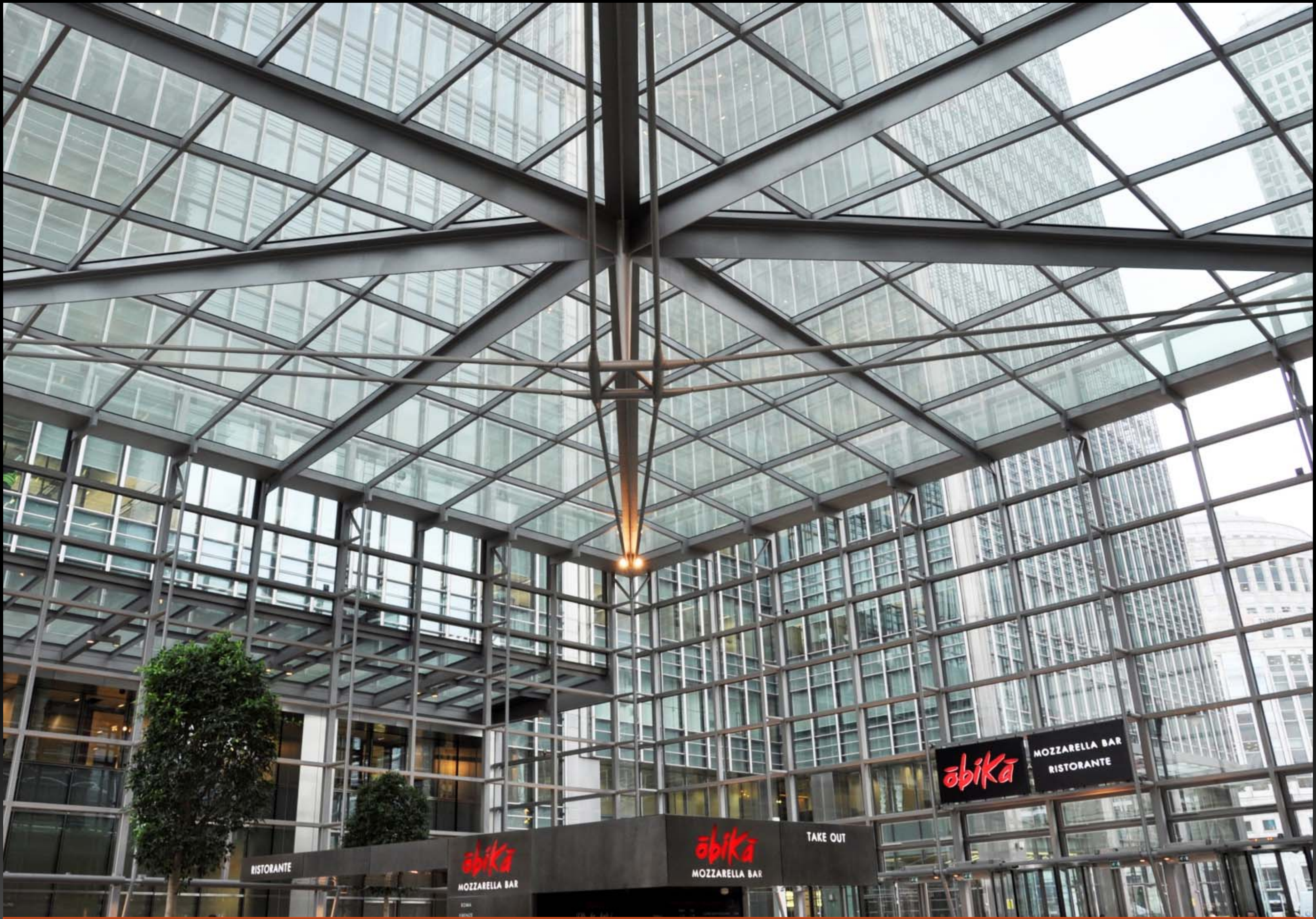
Geometry is skewed for interest. Welded connections keep it all stable.

Bridge support must adjust for movement.

TENSION ASSIST

Innovation in Architectural Steel

This glazed pavilion at Canary Wharf in London uses a highly specialized tensile truss to create a column free support.



This fully glazed room achieves a clear, column free span through the use of a tension assisted roof. The tensile members criss-cross the room and are use to push up through the centre point, allowing the compression members to be quite light.

The custom fabrication for the central support system is quite elegant. If you look closely you can see the weld lines on the roof beams as they were attached to the “star”. London, England. No snow loading!

ARCHED TRUSSES

Innovation in Architectural Steel

Much of the detailing and expression that we see in tension systems came about in the architecture of the High Tech Movement. We need to learn from the mistakes made here to show that steel is indeed a durable material.

The design and detailing on Waterloo Station, designed by Nicholas Grimshaw, are innovative and exemplary – but this fussy, exposed, exterior structure was impossible to maintain, and the train shed is set to be demolished.

Hauptbahnhof Station, Berlin, Germany

Curved, castellated beams with tension support.

The train shed at Hauptbahnhof Station in Berlin uses an exterior tensile structure, but the detailing and materiality are far simpler than for Waterloo Station. The choice of colour here also impacts cleaning. The glass on the shed is able to be cleaned using fairly standard methods.

The trusses continue on the interior to allow for the clear spanning curved beams to be lighter through this “assistance”. The square steel framing that supports the glass roof is also reinforced with X type tension reinforcing.

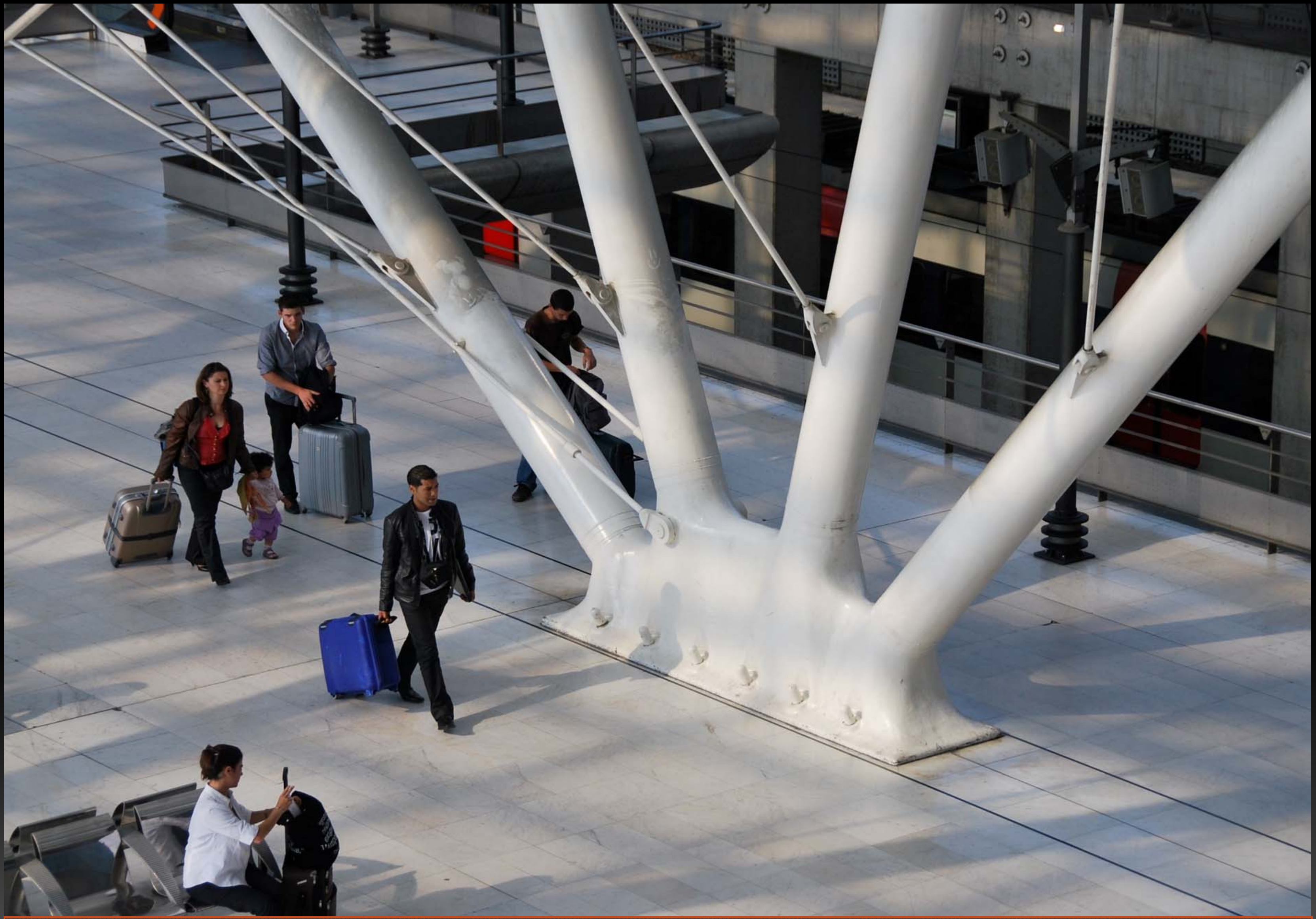
The holes cut in the web make the beam lighter and a bit truss-like. The tension x bracing at the glazing stabilizes the structure.

Here you can see the many different levels of structure in the station. The larger tension system is comprised of cables with cast clevis attachment systems. The station is recent so it will be interesting to see how easy it is to maintain.

Peter Rice, TGV Station at Charles deGaulle Airport in Paris. Inverted bowstring truss.

Dirt build up as the truss is inaccessible for cleaning.

The shape of the truss allows for two central rows of support and a wide cantilever for the balance of the roof.



Cast steel for base support.

Exterior glass walls are also cantilevers. Note the gap between the walls and the roof. Air flows through for ventilation.

Exterior glazed wall support structure. Also using a smaller box truss along the edge of the upper roof to span between the bowstring trusses.

Millennium Bridge, Denver, Colorado

Triangulated truss with suspension system for the bridge platform. Note the asymmetry of the cables.

Simple fabrication of the joints that might appear welded from a distance but actualy have simple lapped bolted connections at the joints.

Detail of connections. The inset plates and cap plates are not made flush to create a less expensive detail.

SUSPENSION ASSIST

Innovation in Architectural Steel

Used when you want to keep the platform light and not supported from below

The relatively lightweight pedestrian bridge platform is achieved by the use of tension cables to support and thereby break up the effective span.

The railing design on the “support” side of the bridge is slightly more opaque and designed to hide some of these details. Tension cables in exposed conditions must be protected from weathering. This is often done by overwrapping both cable and connection.

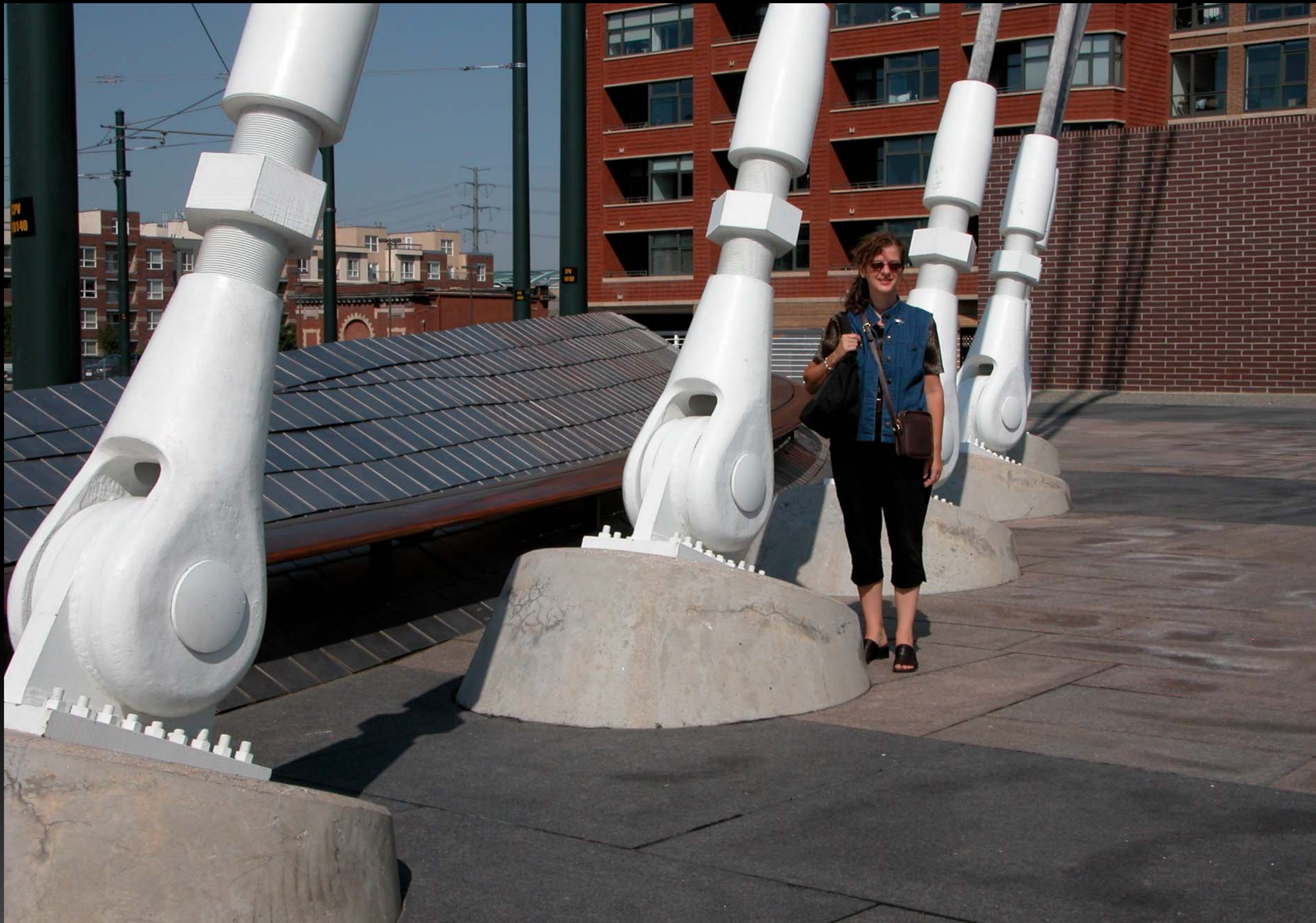
Rather than using a more typical die cast anchor, this bridge creates the connection point through welded plate “boxes” that hide the more standard bolted connection inside (also weather protected).

Pedestrian Bridge, Denver, Colorado – a pair of mast supports is used to suspend the bridge deck symmetrically from both sides.

Fairly straightforward framing is used that is suspended from the cables. To make it more aesthetically appealing, round tubes instead of more standard shapes. Galvanized wide flanges are used where they cannot be seen.

Millennium Bridge Denver, Colorado – single large mast to suspend walkway.

Standard clevis type tension connectors. You can see the weld marks from the butt welds where the round sections are joined.



HUGE clevis connectors for the base of the “cables” that anchor the ties.

A lift bridge in Auckland, New Zealand.

The bridge platform parts in the middle and is simply hinged at either side.

Square custom sections for the inverted V that forms the “mast”.

Base connection of the mast to the bridge platform.

Pedestrian bridge over the Trans Canada Highway outside Vancouver. Two arches, supported at the median, pedestrian deck hung on cables.

Span determined by the ability to have this central pier. Loads are balanced either side as there will be thrust from the arches to be resisted.

Thrust resisted by large concrete abutments at the sides of the span. The deck is supported by a hanging system.

View across the bridge. The arch sections are all custom fabricated from plate steel.

Special T sections were fabricated to hold the deck and provide attachment for the suspension system.

View under the bridge showing the round HSS tube that forms the central spine for the platform support whose sections appear to cantilever out (except not really a cantilever as they are cable supported!)

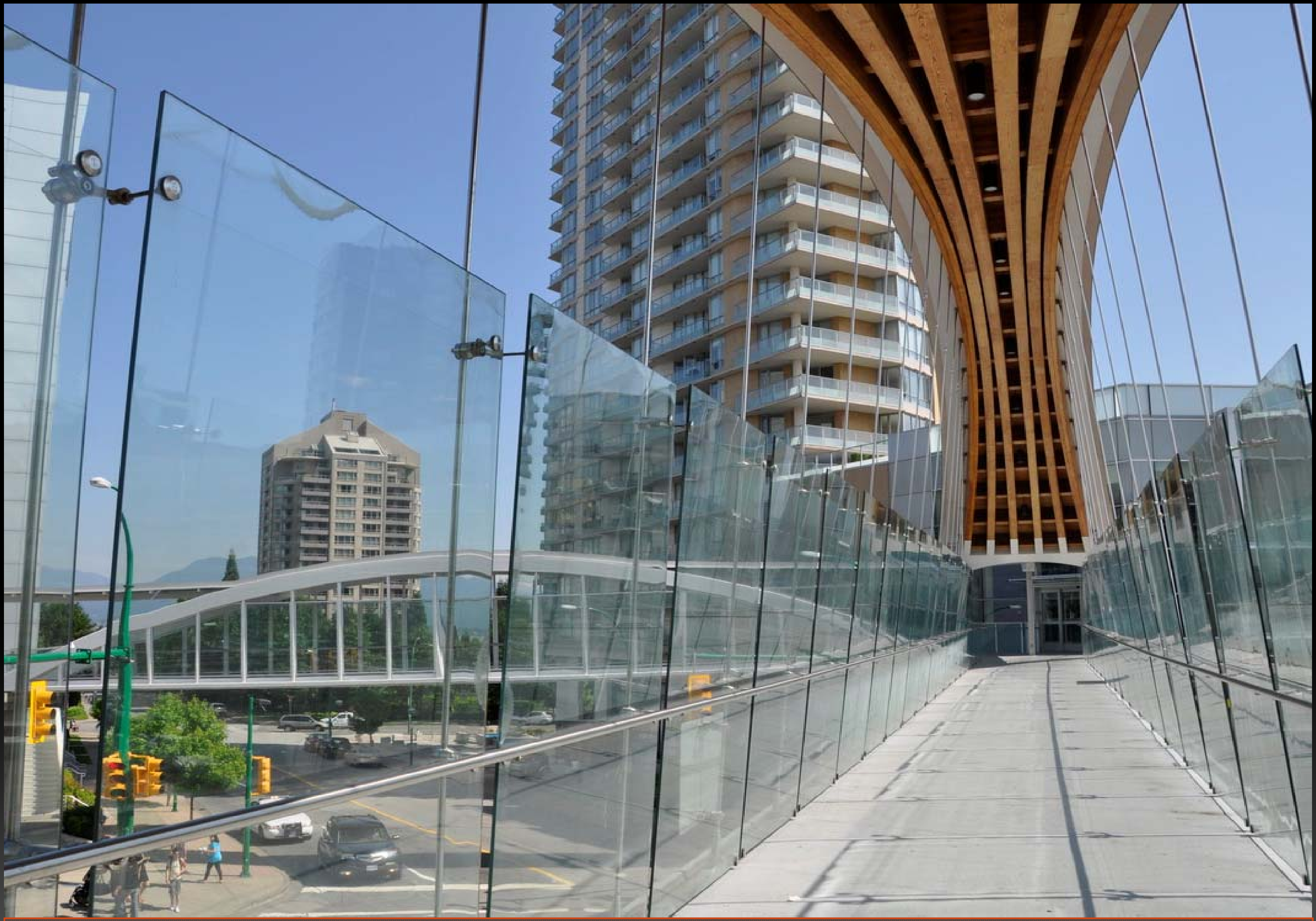
Edge detail from below. See the galvanized decking that spans between the white T beams.

The top curved member is connected in the middle, not so discreetly.

Pedestrian Bridge outside of Vancouver that uses steel and glulam to create an arched structure that supports a platform from cables.

Pedestrian deck is a thin slab of reinforced concrete. The cables also provide attachment for the glazed barriers.

The wood beams are restrained at the ends by a steel structure.



The glass is not sealed to provide ventilation.

Detail where wood and steel meet.

LONG & COMPLEX

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Solferino Bridge, Paris by Mark Mimram

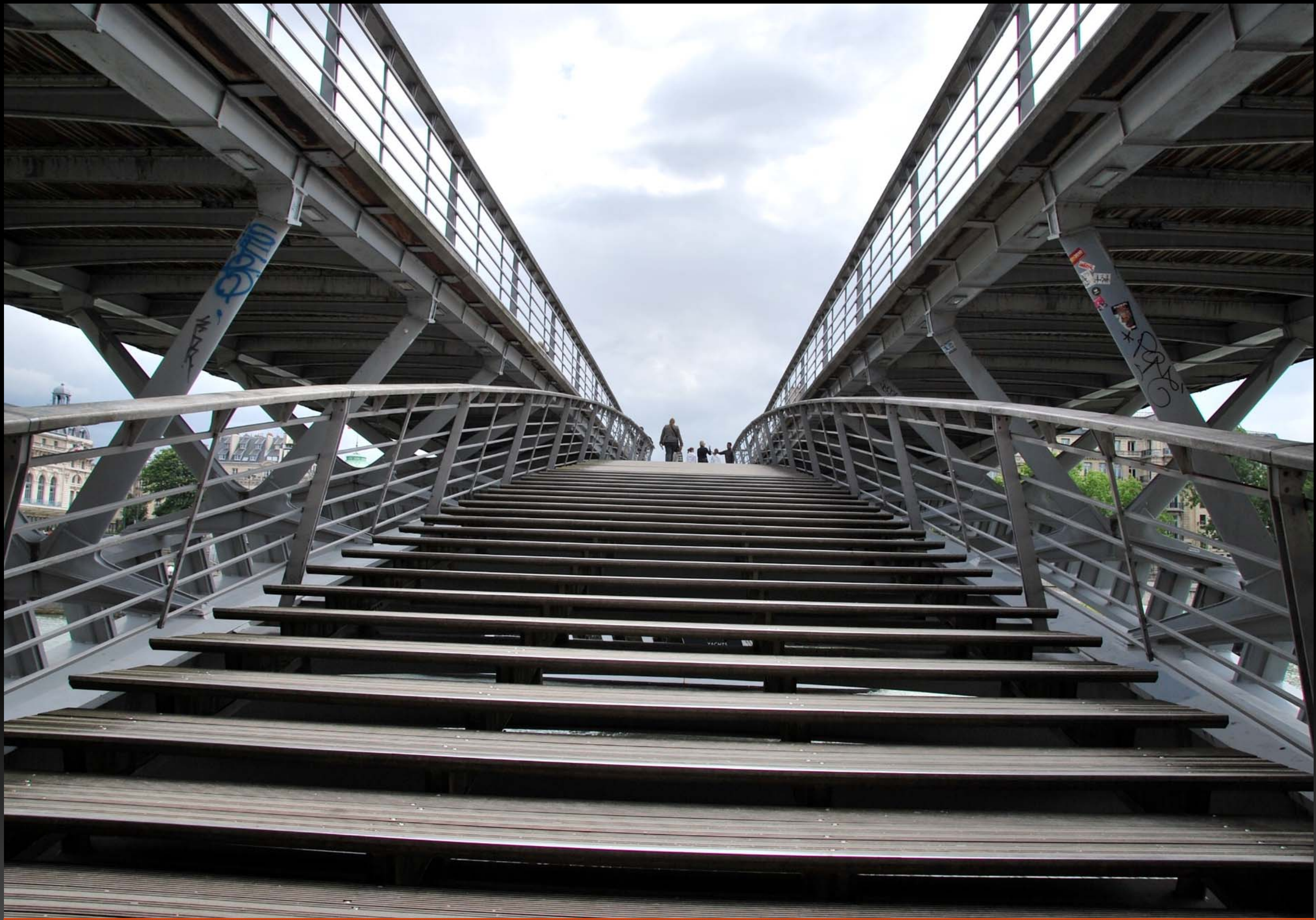
The spans change to allow for pedestrians to access the bridge from an upper and lower level. The V shaped supports are fabricated from elliptical tubes (1:2 ratio always).

Concrete abutments absorb the thrust of the lower section.

A welded square truss is used. The joints must be very strong as there is no triangulation.

Special “feet” to connect the elliptical tubes to the base of the support system.

Custom hinge connection at one of the abutments to connect the upper level to the lower level.



Two paths of travel determine the nature of the span.

Amgen Bridge in Seattle, Washington

Large round HSS tubes create a criss-crossed support system for the walking platform and the partial canopy covering.

The walking deck is fairly standard in its framing. A lot of diagonal bracing in its plane to keep it rigid.

The structure has to resist this eccentricity of loading.

The canopy uses modified truss like members to support the canopy and fall prevention system as it crosses over the rail tracks.

Detail of the connection of the “wall” support system to the upper tube.

From a distance the structure looks much lighter than it actually is. The spans were determined by the availability of the central support point and track condition.

View to underside of bridge. Lots of eccentric, twisting forces to be resisted in this one.

View of underside of bridge showing fairly standard truss arrangement to support walkway.

Simone Beauvoir Footbridge by RFR, Paris, France

Very unique span that had to accommodate ships passing beneath AND being delivered in a minimal number of pieces by ship and passing underneath other bridges!

A resting space inside the bridge showing the construction of the top platform.

View from the other side.

Main connection at the river side to the support system.

Support system where bridge crosses over road at side of span. Note the multiple layering of span conditions.

Photo: Sylvie Boulanger

View at river side to below.

Photo: Sylvie Boulanger

Appreciate the thickness of the steel plate.

Porto Airport, Porto, Portugal

Front façade of airport at the passenger drop off zone

Very large complex triangulated arched trusses clear span across the departures hall.

Bottom chord is round tubular member.

Very light tension below visible truss.

Making a great effort to match the member type and size with the job it is doing.

Lighter steel system is used to create the spanning members that run perpendicular to the large trusses. Closed in on the bottom in panels that allow the expression of the large trusses to stand out. Revealed around the diamond shaped skylights.

Condition at base of truss behind glazed front wall.

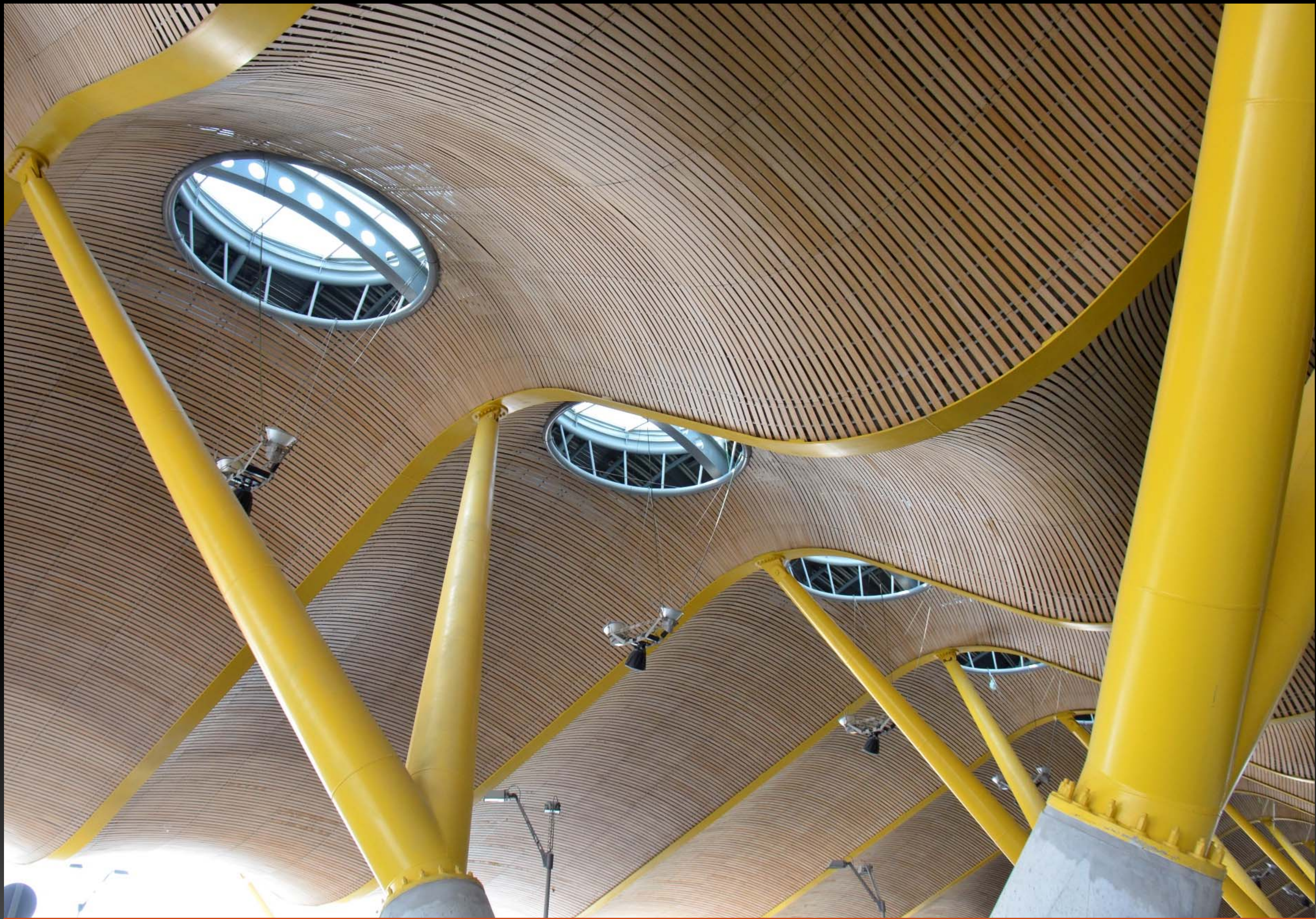
Less elaborate structure in departures area.

Glass at front wall clips to slender steel members behind.

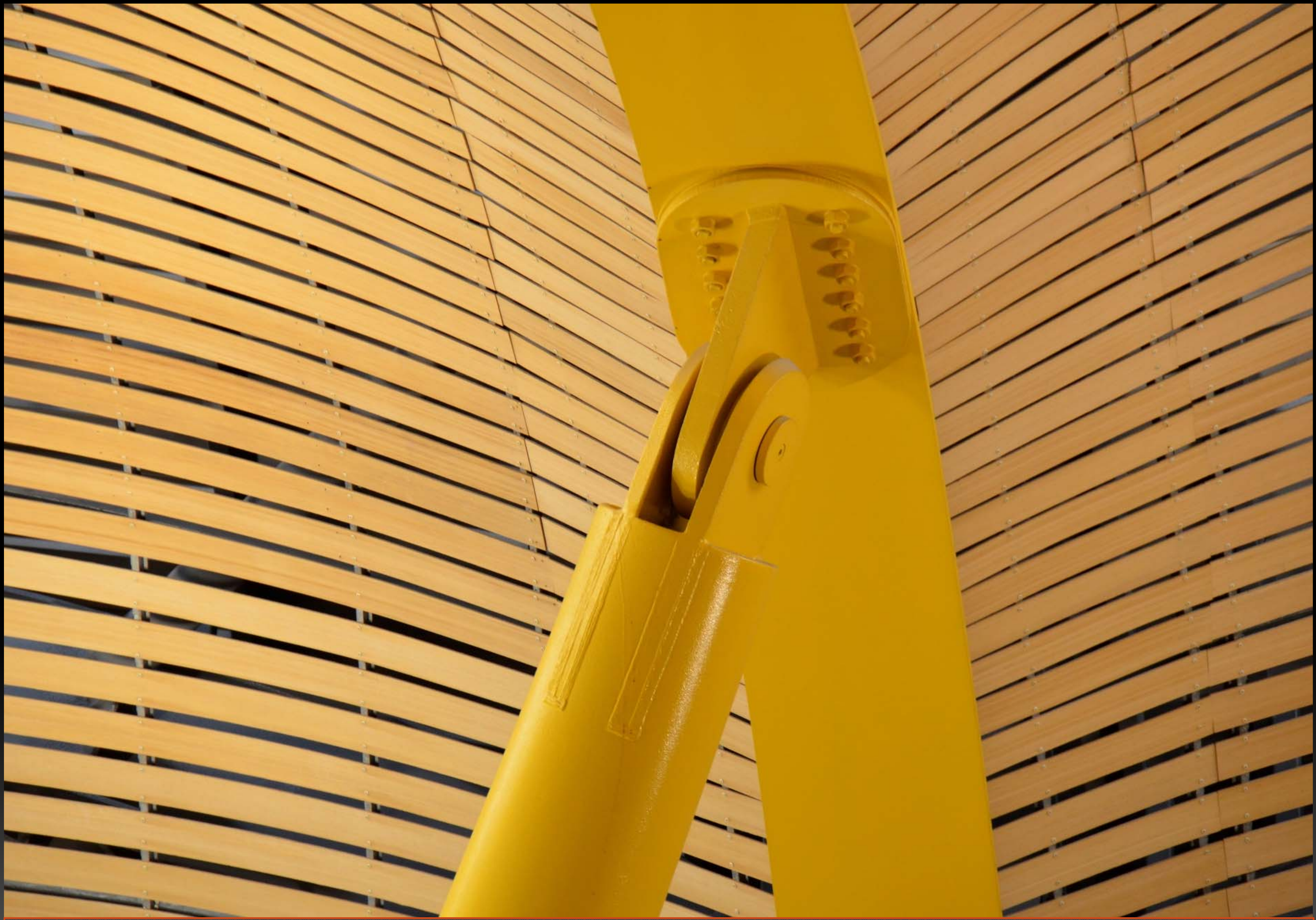
Glazing supported by elliptical tubes that are bolted to the trusses via small plates. Hung from above with stainless rods.

Special attachment for the glass to the elliptical tubes. Does not require penetration of glass as would a typical spider connector.

Madrid Barajas Airport, Terminal 4 by Richard Rogers. The use of the long tapered tubular supports helps to decrease the span of the curved members.



View up to the canopy over the drop off area.



Simple pin connector detail for attachments.

The arched wide flange members have a simple pin connection where they meet at the top of the curve.

The beams cantilever out as the roof extends to perform a shading function.

Alternate support system on the interior. Use of elliptical tubes. Expressed welds.

Even the temporary plate marks have not been removed.

View up into the roof space above the wood ceiling. The secondary support system for the galvanized roofing is visible.

Pedestrian bridge at Lisbon Train Station by Santiago Calatrava. Note these bridges are closed to the public…

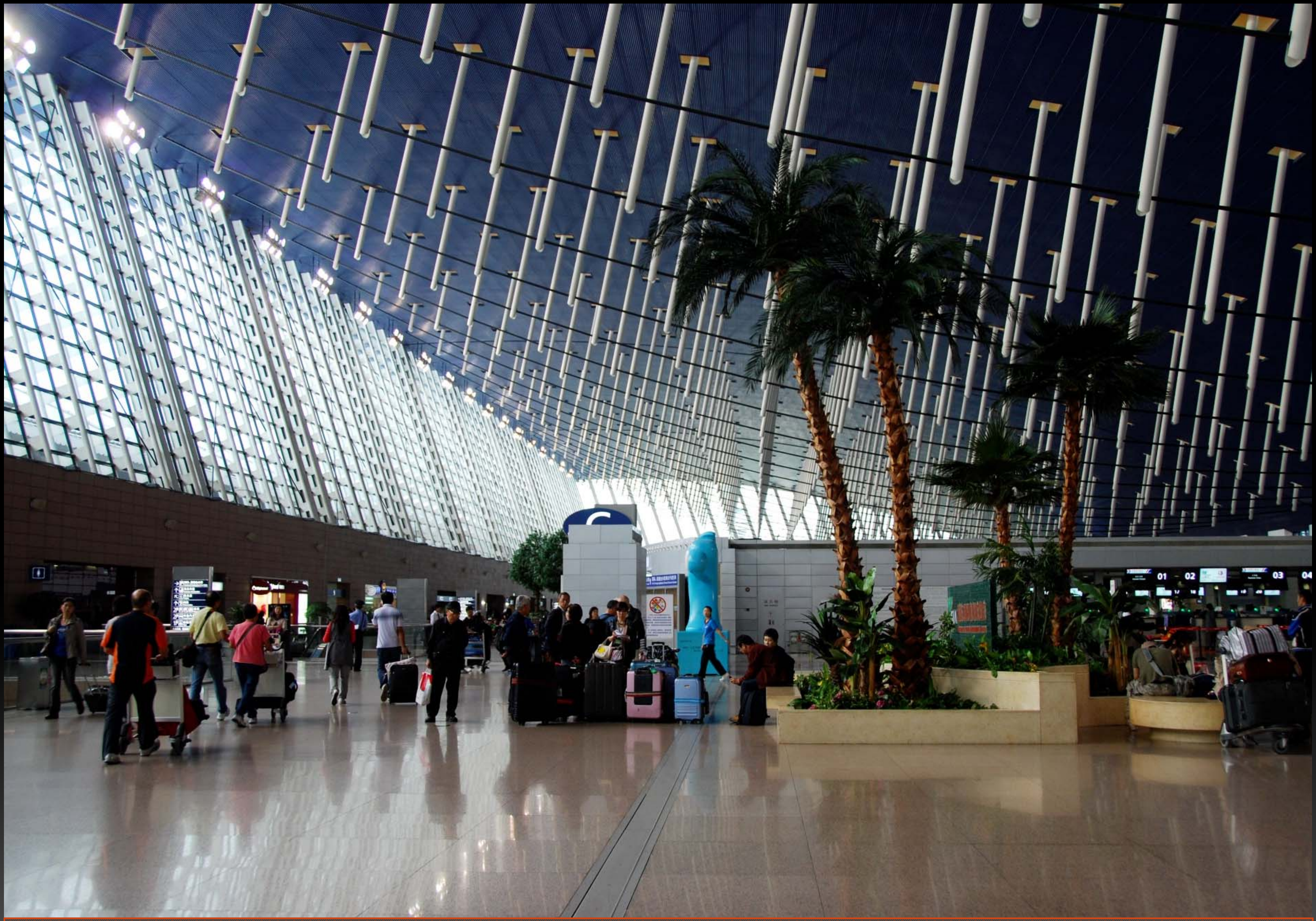
Looking across the bridge towards the train canopy.

Concrete support for the bridge. Bridge structure uses round tubes and tapered wide flange type members.

Side view of bridge as it spans across the plaza and multi lane street.

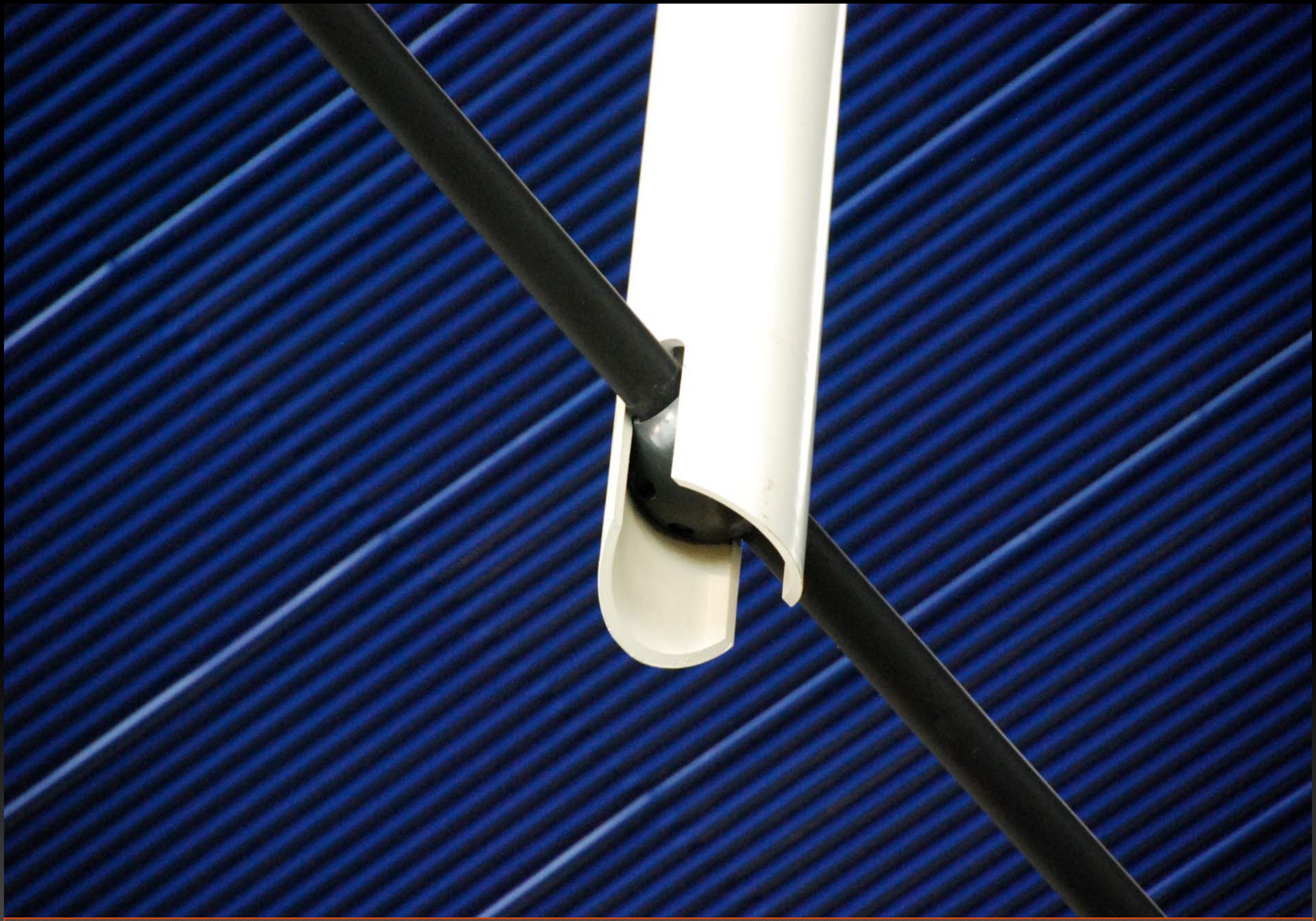
The support system fans out to reduce the span by a fraction.

Very much a fully welded set of details.



Pudong Airport, Terminal 1, Shanghai, China

Trusses are a variant as they are not triangulated. Use a solid top chord with round HSS struts that are connected via a tension system.



Special connector uses fit and not welding or bolting to transfer the loads.

Roof over passenger drop off zone exposes the nature of the structure that is concealed on the interior.

Extensive cross bracing to add stability in the blue plane of the roof members that are all HSS sections. The white struts are pin connected to the blue rectangular HSS beams. The struts and tension system push up on the beam to assist it rather than making a true truss.

Tension Applications

La Defense Paris | 1989

Member Differentiation

- Many unusual geometries are possible through tension support systems
- Tension vs. compression can allow designers to differentiate member size and type
- Systems can include:
  - Rods
  - Cables
  - Smaller sections
    - Standard or high strength structural steel
    - Stainless steel