Smooth Re-Entry

The Entrance Canopy at the Temporary WTC Path Terminal

By Edward M. DePaola, PE, Andrew D. Mueller-Lust, PE, and John Kamocsai, PE

The rebirth of the World Trade Center site began with the new Temporary PATH Station and by the construction of "PATH Plaza", with its soaring 95-foot by 155-foot cantilevered entrance canopy. The design process for this canopy was one of those rare occasions that most Structural Engineers always hope for: a perfect collaboration between Architect and Structural Engineer. The form evolved from only a handful of initial design criteria:

- There would be a 60-foot wide stairway from the street level down to the upper mezzanine.
- The area in front of the stairs would be a public plaza.
- The canopy was to provide as much weather protection as possible for both the stairs and the plaza.

The stairway would be the *only* entrance to the PATH station; the Architect wanted to ensure that the canopy would act as a portal providing a sense of entry. It was important to make it directional, so that the commuter would have no difficulty knowing exactly where to go without the need for any major signage. Because it would be sitting in the middle of a large, open, public plaza there was an obvious desire to limit the number of columns. Finally, to facilitate the economic recovery of Lower Manhattan, the station needed to be designed and constructed to meet a very tight construction schedule.

DESIGN EVOLUTION

The first proposed concept consisted of two "jumbo" columns supporting a large flat plate consisting of a grid of rolled sections with both a roof deck and a ceiling. Because of the large cantilevered spans, it quickly became apparent that the system was not at all efficient. The thought of tapering the steel towards the ends of the cantilevers to save some tonnage was immediately dismissed, since it was obvious that the fabrication costs would outweigh the savings in tonnage. The idea of truss systems was the next evolution.

Jumbo columns were not compatible with the more delicate trusses, so the idea of using a mast system was introduced. The Architect liked the "mast" concept because they could be used as "pylons" or "beacons" which could be seen from larger distances, thereby making even stronger statements of location, directionality and entry. The use of cables was the next logical step (due to their slenderness), permitting the trusses to become even more delicate.

To further enhance the directional nature of the canopy, transverse rib trusses were sloped from the front and rear faces to the longitudinal "spine" of the canopy. Their bottom chords were curved with a termination at the spine truss which lies over the stairway and spans between, and cantilevers beyond the pylons. The result was an elegant, structurally efficient directional structure which provided a sense of entry with virtually no visible signage, as well as weather protection for the stairway and a large part of the public plaza.

The basic structural system consists of:

- Two wedge-shaped masts
- Stay cables
- A "Spine" truss
- Cantilevered "Rib" trusses
- Secondary horizontal stabilizing trusses
- Roof deck

MASTS AND STAY CABLES

The 60-foot tall masts are constructed of varying diameter pipe, 20 inches at the base and 12 inches at the top. The four legs of each mast are 6 feet apart in the north-south direction, but vary in the east-west direction beginning at 15 feet at the ground, 10 feet at the top of the spine truss and coming together at the top to create the basic wedge shape. All of the pipes were bird-mouthed to fit, and fully welded at the joints.

There are eight stay cables from the top of each mast (16 total). The east (or front) cables are 1-1/2 inch diameter and the west (or rear) cables are 1-1/8 inch diameter. The cables are anchored at each end with standard pin connections to fin plates. To facilitate the transfer of load, where the cables attach to the rib trusses, the top chord diagonal pipes were replaced by steel plate. A second steel plate was installed perpendicular to this plate and to the bottom chord, creating a "T" section. The cable's attachment plate was then welded to the top of the "T". This provided clean locations for the attachment of the cables, as well as a simple method for flashing where the plates penetrated the roof membrane.

Cable lengths (including turnbuckles) and forces under system dead load were provided to the fabricator so that, when installed, the canopy edges would be at proper elevation and so that the initial forces in the cables would be known. The cables assist the rib trusses in supporting live loads, snow loads and wind pressures.

TRUSSES

The spine truss spans between and cantilevers 30 feet beyond each mast. It is a three-chord truss that is 7 feet deep and 10 feet wide. The top chords frame into the legs of the masts, and the bottom chord "floats" through them giving the appearance of support only at the top chord. Chord elements are 5 inch diameter pipe and diagonals are 3 inch diameter pipe.

The rib trusses are attached to the spine with standard pin connections to facilitate erection. They are supported at their mid-lengths by the stay cables and then cantilever beyond. Although their widths are constant at 6 feet, the radii of each were varied to create a "gull-wing" appearance. The front trusses extend 53 feet beyond the centerline of the spine truss and have radii of 195 feet at the top chord and 145 feet at the bottom chord. The rear trusses extend 42 feet and have radii of 111 feet at the top chord and 89 feet at the bottom chord. The bottom radii of both the front and rear rib trusses intersect at the bottom chord of the spine truss.

Because of the directions of the cables, force components perpendicular to the rib trusses were generated. To resist these forces, horizontal stabilizing trusses were added between the ribs. As with the other trusses, these were attached with standard pin connections to facilitate erection. Finally, a 6 inch deep cellular roof deck spanned the 24 feet between the top chords of the rib trusses supported on WT sections to give the appearance that the deck is floating just above the trusses. The deck not only acted as the roof surface and structural diaphragm, but as the architectural soffit as well.

To permit more daylight under the canopy, a skylight was added over the center portion of the spine truss. All of the elements were Architecturally Exposed Structural Steel (AESS). Surface preparation was SSPC-SP10 Commercial Blast Clean, and a 3-part high quality paint system was used: a zinc-rich primer, an epoxy second coat and an aliphatic polyurethane gloss final coat.

The temporary PATH station is being treated as a permanent structure. Therefore, the canopy was designed for full New York City Building Code wind and snow loads. Because of the proximity to the open WTC site (the "bathtub"), wind pressures were chosen based on an open exposure and snow loadings took into consideration both sliding and drifting snow.

ERECTION SEQUENCE

The cantilevered and cable-stayed design meant that the erection sequence was an integral part of the design. The plaza level was not designed to be jacked against, so all of the adjustments had to be done by changing the cable lengths. The spine truss was erected first followed by the rib trusses. The tips of the cantilevers were shored by temporary supports permitting the truss-to-truss pin connections to be made.

Next, final cable lengths (including turnbuckles) were calculated based on initial stresses at self weight at 70 degrees. With the rib trusses shored, the turnbuckles were marked at length and were turned a set number of times to lengthen the cable and permit installation of the pins at each end. The turnbuckles were then restored to their original marked length and most of the tips of the rib trusses lifted off (or very nearly lifted off) of their supports. At locations that did not lift off, the shores were lowered. Using this procedure, the final elevations were within tolerances.

FOUNDATION

The economic recovery of Lower Manhattan required that the PATH Station be designed and constructed in a manner that could be implemented quickly to meet a very tight construction schedule. Keeping in mind that this would be a temporary facility, one of the key solutions was to utilize as much existing grid, layout and structure as possible. The exact location of the canopy was determined in part by the underlying existing structural conditions, to maintain the existing sub-grade structure and to minimize direct and indirect foundation costs. As a result, each mast has a considerably different support system.

Each of the two 4-column masts penetrate through the street level, and extend approximately 17 feet below grade and below the existing concourse level. The Northern mast is founded on a 20 x 25-foot spread footing arrangement. In this area, the existing concourse slab is a slab on grade and beam system. The foundation was hand excavated, locally exposing the underside of the grade beams. The spread footing was then cast around the existing grade beam system. This allowed the existing concourse slab in this vicinity to be maintained.

The Southern mast is located over the existing century-old Hudson and Manhattan cofferdam structure. This structure is the eastern-most portion of the former World Trade Center basement levels, and was the original location of the PATH Cortland Street Station prior to construction of the World Trade Center. The mast is supported beneath the concourse level by a series of 30 foot long W33 transfer girders, perpendicular to the longitudinal axis of the overhead canopy.

In order understand the behavior of these two different support systems, a three dimensional computer model was developed, accurately modeling both the soil and transfer beam systems. Consequently, it was ensured that both foundation systems would act in a similar manner, thereby not imposing unexpected secondary stresses in the above-grade superstructure. In addition, a sleeve-type connection was designed for the street level penetrations in order to provide additional lateral support to the structure, while minimizing vertical load to the foundation elements.

Although called "temporary", the entrance canopy will remain in place for approximately four years. Until its eventual removal (which will be as easy as its installation), the canopy will act as an effective signpost marking the public's re-entry to the World Trade Center site.▪

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