FLYING ON THE GROUND

A new monorail system at Newark International Airport is designed to start passengers on a rapid journey

By Robert I. Davidson, R.A., Joseph M. Englot, P.E., and Antranig M. Ouzoonian, P.E.

ARCHITECTURALLY CONCEIVED TO PROMOTE THE PRESENCE OF A NEW PUBLIC TRANSPORTATION NETWORK at Newark International Airport, a new monorail system is a key element in the airport's redevelopment program. The fully automated people mover system, which was funded and managed by The Port Authority of New York and New Jersey, links remote parking lots and car rental services with the three existing terminal buildings and connects them to each other with a peak capacity of 3,000 passengers per hour in each direction. In a planned second phase, the monorail will be extended to interface with New Jersey Transit commuter rail lines and an off-airport mass transit connection along the northeast corridor.

The project actually encompasses substantially more than just the elevated painted structural steel guideway for a typical seven-car train. Also included are four remote parking lot stations, three terminal stations, a car maintenance and storage facility, and ancillary substation structures that provide power to the guideway.

The design vocabulary was to use "structural steel as architecture." The result is a "family of structures" that departs from the poured concrete hyperbolic paraboloid and aluminum curtain wall building envelope of the existing terminals that were constructed in the late 1960s and early 1970s. The common architectural theme was accomplished by using exposed structural steel, steel and glass curtain walls, translucent panel clear stories, and precast concrete building bases as the prototypical building system envelope. The remote and terminal station both consist of a two-story lobby entrance with open vertical circulation up to a platform level, and utility spaces below the platform. The design is intended to maximize views of the airport and, through the visual clarity and openness of the plans, orient passengers towards their destinations. In addition, the open views provide a sense of safety and security.

During peak periods, a seven-car train can depart from a given station every 90 seconds, completing a round trip of the on-airport guideway in approximately 19 minutes.

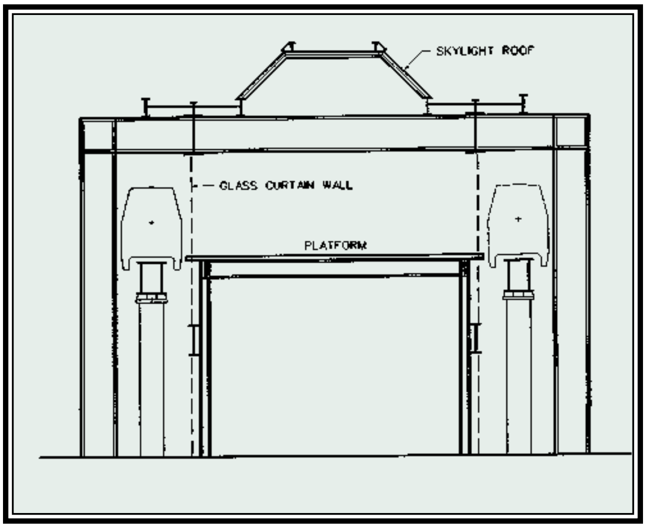
Design and Construction

The system was designed and constructed suing a two-pronged approach. The monorail stations, guideway foundations, maintenance control facility, sub-stations and canopy frontages were designed by the Port Authority Engineering Department and publicly bid as a series of conventional construction contracts. The guideway itself, monorail cars, power system, computer control system and maintenance equipment were bid as a design-build RFQ, RFP vendor package that also included a one-to-five-year contract to operate and maintain the system. Von Roll Transport Sytems, the successful bidder, was later acquired by AEG Monorail Systems, Inc. and then ADtranz. Technical performance criteria for the design-build contract were prepared by Port Authority engineers working with the firm of Lea and Elliot Associates.

With the exception of stretches of the guideway within an existing elevated right-of-way ont he air-side of the three main terminal buildings at EWR, the monorail stations were designed to be architecturally and structurally independent from the guideway and its supporting columns. This defined a clear point of separation for the two independently designed and constructed portions of the system and led to relative ease of coordination.

By designing the stations with a center platform, the guideway structure passes on either side of the stations. The sliding glass doors in the platform's window wall enclosures, which align with the vehicle doors for boarding, are the only shared elements. All stations, as well as the monorail vehicles themselves, provide complete weather protection for passengers including heating, ventilation and air conditioning.

Foundations for the entire system, other than the Maintenance and Control Facility (which used timber piles), were designed and constructed using 100-ton-capacity steel pipe piles, 12" in diameter, with a fusion-bonded epoxy coating.

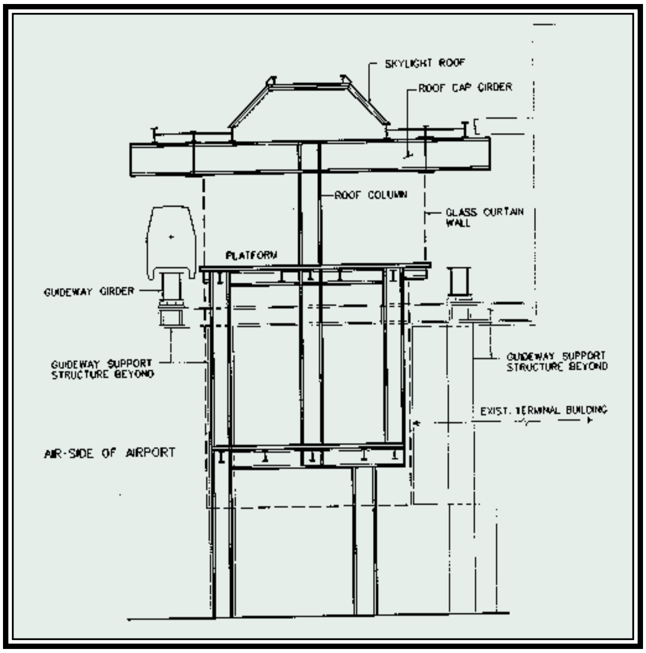


The for remote stations are both beautiful and functional. The brightly lit buildings serve as beacons for travelers and as points of safety. Photo courtesy of the Port Authority of New York & New Jersey.

Station Structural Design

Four remote stations in the long-term parking lots serve as entry points to the current first phase of the monorail system. Besides parking patrons, passengers dropping off rental cars and those dropped off from nearby hotels have access to the remote stations, thereby reducing traffic on the terminal frontage roadways. The remote stations bring patrons to the guideway level—24' above street level—via escalator and elevator.

The center platform is supported by an independent, steel-framed structure that also supports the lower portion of the building's glass curtain wall and is nested inside a larger and independent exposed steel rigid frame. The frame's roof girder penetrates the curtain wall to frame into laterally stiff, exposed exterior built-up wide flange columns and take on the appearance of flying buttresses.



The three main terminal stations were designed to fit into "notches" that were built in the terminals during the 1970s to accommodate the long-anticipated monorail construction.

Rigid welded joints with stiffeners at the exposed roof girder-to-column connection give the feeling of a stable but elegant structure. The guideway steel box girder—supported on its own set of steel box columns—fits neatly between the row of exterior buttress columns and the station curtain wall on both sides of the platform. Besides visual independence of the guideway structure, the structural isolation of the two systems prevents vibrations from being transmitted from the guideway to the platform.

Use of uniform depths, widths and thicknesses of steel on the exposed elements and a state-of-the-art paint system eliminates costly metal cladding of girt, roof purlin and skylight framing elements and makes reduced total construction costs on the project. Each remote station used 408 tons of steel. Low bid on the station portion was $17 million, including the superstructure and all finishes. The pile-supported foundations were constructed in an earlier contract along with the guideway foundations, and the foundation cost for the remote stations was approximately $2 million. Three fabricators worked on the remote stations, including AISC-member Kline Iron & Steel Co., Inc. Erector for the remote stations was Universal Steel Erectors, Hightstown, NJ.

Terminal Stations

All three main terminals have a "notch" or right-of-way at the second floor level on the air-side (plane gate apron) of each building. This "notch" was part of the original terminal construction designed by the Port Authority Engineering Department circa 1970 to accommodate a "future people mover." The current monorail vehicles represent a "smaller technology" system running with seven car trains at close headways that was able to meet the specified system passenger volume while still fitting into the existing "notch". Using the existing design save extensive costs associated with reconstructing the air-side of the terminal. The new guideway beams were supported on the independent steel cap beams and columns constructed in 1970 for the "future" guideway without major modifications.

The terminal station as originally conceived in the 1970 design was based on side platforms but the new monrail design called for center platforms. As a result, the external guideway beam alignment was moved outward from the air-side of the building in the vicinity of the station to fit the platform and station itself against the existing building. To accommodate the alignment, the precast fascia of the existing building was removed locally.

The terminal station platform is elevated roughly 45' above the tarmac, providing breathtaking views of the air-side of the airport. It is constructed of rigid frames with an exposed center roof column and roof cap girder to form a tee shape. The lower portion of the transverse rigid frame bent jogs away from the building at the first tier to accommodate the existing building geometry. Again the guideway is supported on independent columns. New box columns were provided where the external guideway beam moves away from the existing building as its alignment approaches and leaves the stations. The platform level can be reached by elevators and escalators.

The use of structural steel permitted quick and easy construction on the active air-side of the terminal—a crucial consideration in a busy airport. The monorail station was designed to be seismically independent from the existing building. As with the entire monorail system, the stations were designed for seismic forces and wind load. Drift criteria governed for the lateral rigid frames with a roof height-to-base width of 3:1.

As with the remote stations, glass window walls enclose the platform level and interstory drift control was critical to permit unobstructed operation of the sliding glass doors to the vehicles.

Each terminal station contains 429 tons of structural steel. The low bid for all three terminal stations was about $15 million including finishes and exclusive of foundations, which were constructed earlier at a cost of approximately $1 million. Fabricator and erector on the terminal stations was AISC-member Helmark Steel, Inc.

Maintenance and Control Facility

The MCF building houses the computers and control equipment for system operation, as well as train storage, train service lifts, a train car wash, storage and loading dock facilities and offices and lockers for system operations staff.

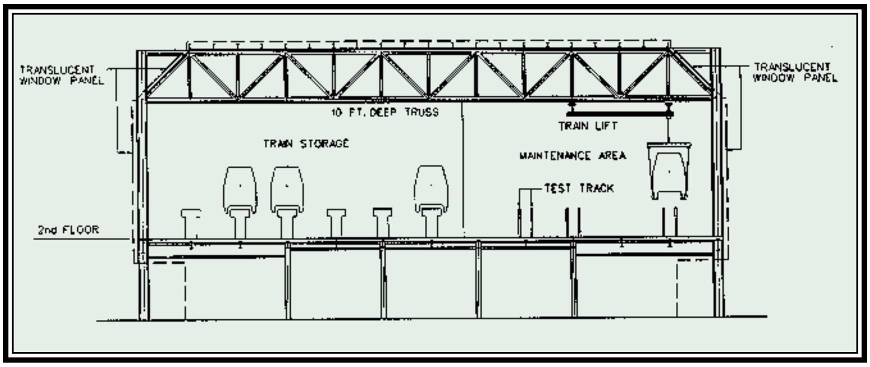
The building measures 330' by 120' in plan and 60' in height. The requirement for column-free space on the second floor dictated 10' deep roof trusses spanning 120' and resting on buildings spandrel wall columns. The top chord and end vertical of the truss penetrate through the building envelope and are exposed steel with inclined translucent window panels between the truss end diagonals, forming a spandrel skylight at the roof level.

The roof trusses also are exposed at the ends of the buildings with translucent panels framed between the planar truss members.

Additional bands of translucent wall panels along the sides of the building allow a profusion of natural light to penetrate the second floor work area and also emit a warm glow at night when interior lights illuminate the building. In the long elevation of the building, two bays of cross bracing at the mid-point of the building can be seen through the translucent panels.

The second floor is at guideway track level. Trains enter the building on the guideway track and are driven onto the transverser, which allows access to seven storage tracks and two maintenance tracks. Entire cars be hoisted into or out of the building through huge rear loading dock doors by a moveable 10 ton crane.

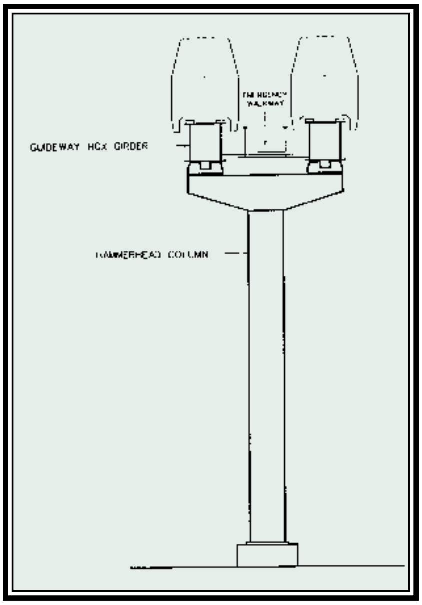
The total amount of steel used in the building was 1,330 tons. The low bid for the entire building, excluding equipment supplied by the monorail vendor, was approximately $9 million. Fabricator and erector on the MCE was AISC-member Helmark Steel, Inc.



Unlike many maintenance buildings, the new Maintenance and Control Facilit y was designed with both aesthetics and functionality in mind.

Guideway Structure

Monorail trains travel on an elevated track varying in height from 18' to 46' above the ground at a nominal speed of 27 mph on a supporting system of welded steel (ASTM A709 36 or 50) box girders 3'-1" wide at top and varying in depth from 2'-3" to 5'-4". Between expansion joints, the tracks form a continuous beam that rides over welded box, tee-shaped steel supports. These hammerhead columns are 15.5' wide and spaced 60' to 90' apart—with some spans up to 155'. The guideway assembly includes power and signal rails mounted on guide-beams and an open-grate steel emergency egress walkway between the double loop of tracks. Each box member is continuously welded so that the interior is deprived of oxygen to prevent internal rusting. On the mainline sections of the guideway, the minimum curve radius is 400', precluding the need for superelevations and significantly simplifying fabrication and erection. The maximum grade on the system is approximately 2-1/4%. The box girder curves along with the horizontal alignment and has spiral transitions where curve radii change. In all, 4,600 tons of steel was used in the guideway superstructure, exclusive of guideway switches. Guideway erectors were AISC-member Owen Steel and a joint venture of



The monorail itself consists of box girders atop a hammerhead column.

Caribe/Helmark Steel. Fabricator for the terminal hammerhead and columns was AISC-member Canron Construction Corp. and erector was AISC-member Helmark Steel, Inc.

Basler & Hoffman of Zurich, Switzerland, did the structural design of the guideway. Weidlinger Associates, New York City, the project's engineer of record, made significant contributions to the design, particularly in the design of the bearings that transfer loads from the girders to the hammerheds and in adoption of the "European" design to American steel detailing and fabrication practices. The design also conformed to AASHTO requirements for highway bridges. Numerous load combinations were analyzed, considering dynamic impact factors of 10% for stress checks and 6% for deflection checks. Dead, live, centrifugal, acceleration/braking, temperature, friction, snow, wind, and earthquake were the basic loads considered.

Individual girders were fabricated and pre-assembled in the shop and tolerance reports were prepared during the progressive trial assembly to minimize field weld splice incongruities. Tolerances conformed to the requirements of AISC's Code of Standard Practice except where the dynamic interaction of the vehicle with certain areas of the girder called for more more stringent tolerances specified by AEG.

Since the entire guideway was designed for two million cycles, fatigue was an important consideration in all aspects of the project, from specifications for fracture critical material and welding to assessment of all structural details to meet AASHTO requirements for fatigue stress range. Charpy V-Notch impact tests were required for all steel, non-redundant main load carrying components subjected to tensile stress. Welding was in accordance with AASHTO/AWS D1.5 and the Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members.

As with any automated system, there are strict tolerances and alignments to be maintained. When coupled with camber and temperature requirements, these constraints made the field welded splices of the box girders near the columns a particularly complex problem. Extensive joint fit up measurements were taken to verify its acceptability before executing fracture critical complete joint penetration welds. Subsequently, all splices were NDT inspected.

Heated Guideway Running Surface

The system features a skin-effect heating system with ferromagnetic tube (Carbon Steel Schedule 40 Pipe) welded to the underside of the running surface and a current carrying heat resistant copper conductor passing through the pipes. These conductors are pulled through the heat tubes and are connected to an alternating current power source at one end as well as to the pipe itself at the other end. The alternating current flows through the conductor and back along the inner surface of the heat tube. The current flowing through the heat tube concentrates only on the inner surface of the pipes; current or electrical potential does not exist on the outer surface of the pipe. The system was developed by Thermon Manufacturing Company, San Marcos, TX.

The structural components of the heating system were fabricated in the form of a three-legged channel for each tire track with a flat running surface formed by a ¼"-thick steel plate supported by 1"x1/2" bars. These "channels" are welded in a paralleled alignment to the top flange of the guideway steel box girder forming the parallel running surfaces for the train rubber tires. Sections approximately 30' in length are put in place to make up the entire girder. The heating pipe of adjacent sections are spliced at each assembly junction (shop splice) and a cover plate is welded in place over the access space, which is left open at the end of each channel section to accomplish the splicing. The channel plate ends approximately 16" from the end of the girder to accommodate the field splicing. The entire beam is transported to the site, complete with the heating pipe system in place. In the field the "field splice" access area was bridged with ¼" plate.

Guideway Switches

Along the guideway are 10 crossovers between the two guideway track beams that carry vehicles in opposite directions. To achieve vehicle crossover capabilities, rotating guideway switches supported by an elevated steel frame were used. Typically, the elevated structure has two 91' spans with 6'-deep plate girders at the outer edges supported by box column hammerheads or bents on pile foundations. Spanning between the plate girders are the W36 frames, which support the rotating guideway switches and the fixed box track girders. A secondary frame above the W36