Left: More than 400 trains—Amtrak, Conrail, and New Jersey Transit—pass through the project area each day.

Below left: Construction of the main span over Amtrak's busy Northeast Corridor was completed between 2 a.m. and 4 a.m. to minimize the impact on train traffic.

Below right: The new viaduct being constructed within several feet of the old viaduct.

GATEWAY TO NEWARK

Maher A. Sidani, P.E., and Bruce K. Riegel, P.E.

The New Jersey Department of Transportation's (NJDOT's) $250 million Route 21 viaduct replacement project in Newark involves a massive bridge crossing, a maze of tightly curved ramps and complex highway improvements on connecting routes. Built in 1932, the original Route 21 viaduct has become structurally deficient and functionally obsolete. When construction of its replacement is complete in late 2003, nearly 29 million pounds of structural steel will carry 85,000 vehicles per day across a wider, safer, greatly improved "Gateway to Newark."

The Route 21 viaduct replacement is remarkable for more than its sheer mass. The urban project area complicated design decisions and construction techniques throughout each phase of the project. The bridge touches down in heavily developed areas and spans even more complicated development: 10 lanes of Interstate 78, three Conrail lines, Amtrak's electrified Northeast Corridor (NEC) and New

Jersey Transit tracks. More than 400 trains pass through the area each day, making it one of the busiest corridors in the nation.

In addition to train traffic, vehicular traffic is very heavy in the area. The original viaduct is just 6' from the new bridge and will remain in service throughout construction. Heavy traffic on connections to Interstate 78, NJ Route 22, NJ Route 1 & 9, Newark International Airport and Newark's McCarter Highway has to be protected and maintained while crews improve the highways and construct a series of complex access and exit ramps.

Design alternatives

To accommodate the many site restrictions, the project team conducted a comprehensive analysis of possible structural design schemes, methodically evaluating their engineering feasibility and constructibility. The Princeton, NJ, office of Michael Baker Jr., Inc., served as the prime design consultant and performed the detailed design optimization process. For the NEC crossing alone, the team evaluated 67 possible alternatives with different pier locations, span length configurations and other structural variations.

The span lengths were determined by combining the superstructure and substructure optimizations, which were developed separately. The substructure optimization included factors such as profile variations and geotechnical conditions. At the NEC crossing, a steel three-span continuous unit

Top: Structural steel for the northbound and southbound structures looking toward Newark.

Left: New Route 21 Viaduct over Amtrak's Northeast Corridor with the original viaduct in the background.

Right: Construction begins on the southbound structure, just west of the original 1932 viaduct. The original viaduct remains in service during construction.

Steel girders on the Route 21 viaduct replacement are curved and must resist high torsional and seismic forces.

emerged as the preferred alternative, with spans of 210' - 270' - 210'. Steel was also selected for the other segments of the project, including the tightly curved ramps.

Even after steel had been selected, important design decisions remained. Constructibility had to be considered very early in the design process so that the design could actually be built amid all the site constraints and staging requirements. Contractors faced not only physical obstacles to their work but also a time crunch measured in minutes, not just days to completion. Construction over the NEC had to be performed between 2 a.m. and 4 a.m. to minimize disruption to Amtrak trains. Therefore, constructibility reviews had to evaluate not only whether or not the viaduct could be constructed as designed but also whether it could be constructed within the authorized two-hour windows.

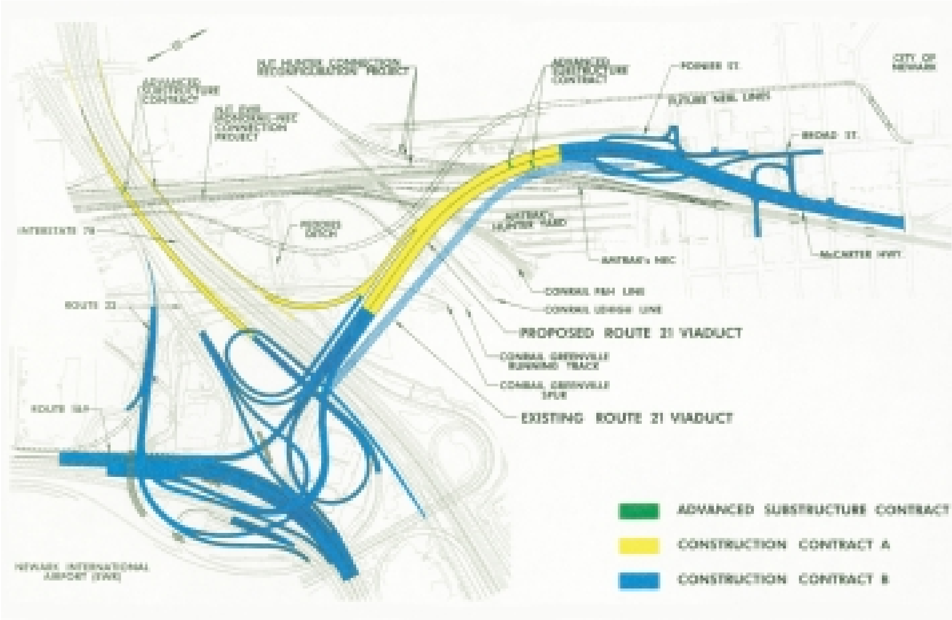
Baker's design allowed the contractor to select either traditional crane construction or incremental launching, which would be complex due to the long spans but would help avoid the many obstacles below the viaduct. Traditional construction from the ground using high capacity ringer cranes was eventually made possible when the NEC's overhead catenary wires, which would have interfered with a high boom, were moved as part of another project. Had incremental launching been used, the 270' span would have resulted in the longest-ever incrementally–launched steel girders.

Design software

Software tools used included Intergraph Corporation's InRoads SelectCAD (version 7.2) and its complementary Bridge SelectCAD program. Once the pier locations, span lengths and basic structural scheme were established, Baker optimized the number of girders and their depth. After Baker's highway engineers had set the horizontal and vertical geometry, the bridge group added the complex curved structures and the intricate three-dimensional surface model, cross-referencing the highway geometric design into the structural design. The team used InRoads to draw the bridge framing plans and then used software from Bridge Software Development International, Ltd. (BSDI) of Coopersburg, PA, to complete the final design. BSDI was selected because of its ability to handle complex geometry and base calculations on a true three-dimensional analysis. However, in order to use BSDI, it was necessary to calculate that complex geometry. Coordinate geometry software (COGO) is typically used, but Baker accelerated the process by using a combination of InRoads (version 7.2) and Microstation CAD (version SE) to calculate the lengths, areas and other necessary data, saving three days of design time for the average bridge unit.

To keep design work consistent across a large project team and a multi-phased project, Baker developed a project-specific design manual. The manual was based on NJDOT design standards and was expanded to include details on elements such as the substructure,

Cranes place girders for the southbound structure. The steel girders are 9' deep and reach spans up to 270' long.



crossframes, bearing stiffeners and design methodologies for curved girders. Formatting instructions and file-naming conventions were also established so that project documents would have a unified look.

Design solutions

The final design of the NEC crossing called for separate structures for northbound and southbound traffic, with three-span continuous curved steel plate girders that are uniformly 9' deep. The northbound spans are 210' - 270' - 210', and the southbound spans are slightly shorter at 188' - 239' - 188'. Girder curves range from 1,538' to 1,657'. The main span is 71' high to provide the required vertical clearance over Conrail's elevated Lehigh Line, which crosses diagonally over NEC tracks. The web depth is 112". Baker used 336 bolted "X" crossframes to carry the torsional forces of the curved girders, with the end crossframes and crossframes over continuous piers designed to carry seismic loads. Top and bottom flanges range from 20" by $1^{1}/_{8}$" to 24" by 3". The structural steel is AASHTO M270, grade 50W. Six 4"- diameter telephone conduits were attached to the crossframes in the northernmost bay of the southbound portion of the viaduct. Drainage scuppers were attached to the fascia girders, and drainage pipes were installed through the crossframes. Exit and access ramps are tightly curved due to space constraints, with flared girders and radii as tight as 230'. The design includes nine bridge-mounted sign structures.

While design elements were kept as consistent as possible, certain portions of the structure required special design solutions. For example, there were significant seismic considerations on the project due to Newark's proximity to offshore faults. While seismic analysis primarily affected the substructure design, it also revealed that certain portions of the superstructure would have to resist especially high seismic forces. One location in particular had an enormous seismic load, so the end diaphragm is designed as a full depth plate girder rather than a crossframe. At another location, torsional forces were so high that a rolled I-beam crossframe had to be used. That made the bridge structurally sound but introduced another problem: the I-beam crossframe makes an inviting roost for pigeons. Baker's design included a pigeon shield at that crossframe to discourage occupation by birds.

Designers also planned carefully for future maintenance and the longevity of the structure. NJDOT specified unpainted weathering steel to reduce maintenance requirements, although the ends of the girders were painted to minimize damage from deicing salts and water flowing through the joints. Since weathering steel eventually causes rust stains on the concrete piers and abutments below, Baker used drip plate details on the fascia girders to direct rainwater away from the substructure and reduce future staining of the piers.

To make bridge inspections easier and safer, Baker designed handrails that are attached to the girder web on each side of the interior girders and the inside of the fascia girders. Designers also made provisions for future bearing replacement. In the locations where the girder is continuous, Baker designed a jacking stiffener on either side of the bearing stiffeners. At the end of the girders, a jacking stiffener was placed near the bearing stiffener. If bearings need to be replaced at some point during the bridge's life, contractors can jack the girders and replace the bearings with relative ease.

Fabrication of the enormous curved girders required careful attention to detail. Often on projects with complex curved girders and construction constraints, oversized holes are used on the diaphragms to make assembly easier. However, the contractor for the Route 21 viaduct replacement chose to use standard $^{15}/_{16}$" diameter holes. That forced the contractor to be precise when erecting the superstructure and prevented the compounding of errors and construction problems that result when the placement of each girder is slightly inaccurate. Standard-sized holes also prevented stability problems when the girders were erected. Since there was no room for error on the curved bridge units that would be erected in limited construction windows over railway tracks or roadways, each of those units was pre-assembled at the fabricator's yard and inspected by Baker engineers to ensure smooth assembly on site.

Construction of the Route 21 viaduct replacement was divided into three contracts. Pile-supported footings for four of the piers were constructed just a year into the design process under an advance substructure contract so they would be finished before new track was laid alongside them as part of a separate Amtrak and New Jersey Transit expansion project. The main span, a ramp to Interstate 78, and lane widening on parts of I-78 made up Contract A, which was completed in September 2000. Both ends of the bridge and the majority of ramps and highway improvements are part of Contract B. Construction for Contract B is scheduled for completion in late 2003.

Baker worked closely with the contractor for Contract A to establish the erection sequence of the NEC crossing superstructure to ensure that work could be completed between 2 a.m. and 4 a.m. The contractor used a ringer crane and two additional cranes to lift the girders. Crews set one girder up, tied it with chains to hold it against the wind and then had to erect a second girder the same night for support. Due to careful design, fabrication and construction coordination, construction proceeded smoothly, and there was no unscheduled disruption to Amtrak service. Similar planning has also led to smooth construction to date on Contract B, despite complex curves and challenging maintenance of vehicular traffic on the many routes affected by the project.

When the Route 21 viaduct replacement concludes with the demolition of the old viaduct, the new Gateway to Newark will be a relief for motorists and a major accomplishment for NJDOT, one of their largest recent projects. The impressive structure tiptoeing through a heavily developed area is proof that even on projects of enormous proportions, it's the details that yield a "super" structure.

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OWNER:
New Jersey Department of Transportation

STRUCTURAL ENGINEER:
Michael Baker Jr., Inc.,
Princeton, NJ

FABRICATORS/
MANUFACTURERS:
Girders: High Steel Structures, Inc., Lancaster, PA (AISC member)

BEARINGS:
The D.S. Brown Company, Inc., North Baltimore, OH, (AISC member) and Amscot Structural Products, Inc., Dover, NJ (AISC member)

MODULAR JOINTS:
The D.S. Brown Company, Inc., (AISC member) and Watson Bowman Acme Corp., Amherst, NY (AISC member)

STEEL DETAILER:
High Steel Structures, Inc.,
Lancaster, PA (AISC member)

SOFTWARE:
InRoads, InBridge, Microstation CAD, BSDI, SEISAB, STAAD III