Carrying 280,000 vehicles per day, this interchange in northern New Jersey features two plate-girder flyover ramps and was rebuilt in only 13 months.

Flying High

Rama Krishnagiri, Edwin Skrobacz, and Richard Szatkowski

Both NJ Routes 17 and 4 are major roadways in Bergen County, NJ, and their interchange is surrounded by dense commercial development. The estimated traffic volume in this project corridor is approximately 280,000 vehicles per day, leading to significant gridlock. Reconstruction of the interchange increased NJ Route 17 from seven to eight lanes and increased NJ Route 4 from eight to 12 lanes.

BRIDGE DESCRIPTIONS

A major improvement at the interchange is the reconfiguration of the existing cloverleaf ramps and elimination of one of the loop ramps.

Ramp SE is a sharply curved, nine-span, single lane off-ramp bridge at the top level of a three-level interchange connecting Southbound Route 17 to Eastbound Route 4. The ramp radius varies from 100 m (328 feet) to 279.80 m (918 feet), with a slight reverse curve at its eastern end. The 325.50 m long (1068 feet) structure is comprised of three-span continuous, steel curved girder units. Ramp SE is on a crest vertical curve with 4.5% approach grades. The ramp profile was largely dictated by the minimum vertical clearance over Route 17 (4.80 m (15’-9”) minimum mandated by NJDOT). To limit the profile, an integral expansion pier (supporting expansion bearings) with dapped girder ends was utilized over Route 17.

Ramp NW is a single lane on-ramp at the top level of the three-level interchange providing a link from northbound Route 17 to westbound Route 4. It is 263.65 m (865 feet) long with two sharply curved end sections and a tangent section in between. This seven-span steel curved girder bridge is composed of a four-span continuous and a three-span continuous unit. Ramp radius is 100 m (328 feet) at the curved segments.

Both ramps SE and NW have similar cross sections: an 8.0 m (26’-3”) wide roadway bounded by 0.53 m (1’-8½”) wide NJ barriers. The roadway is superelevated at 4% on Ramp SE and the superelevation on Ramp NW varies from 2% to 4%. Each ramp has four girders spaced at 2.50 m (8’-2½”) with a 0.78 m (2’-6½”) deck overhang, supporting a 24.2 m (9½”) structurally one-course deck slab with a corrosion inhibitor. For both fly-over ramps, span lengths and substructure arrangements were set to maximize span lengths for the depth available in order to limit the number of piers.

Route 17 over Route 4 is a 2-span continuous bridge comprised of rolled steel stringers with cover plates. Each roadway cross-section is similar, providing a clear width of 16.76 m (55’-0”) with 0.53 m (1’-8½”) wide NJ barriers on each side. Eight rolled steel stringers spaced at 2.34 m (7’-8”) support a 222 mm (8¾”) thick one-course deck slab, with variable deck overhangs.

Connector Road over Route 4 is a 2-span continuous structure comprised of welded steel plate girders. The roadway cross section provides a clear width of 13.54 m (44’-5”) and is bounded by a 0.53 m (1'-8 1/2") wide NJ barrier on one side and a 1.83 m (6'-0") wide sidewalk and 0.31 m (1'-0") wide parapet on the other side. Seven steel welded plate girders spaced at 2.44 m (8'-0") on centers support the 216 mm (8 1/2") thick single course deck slab.

DESIGN CONSIDERATIONS

During the conceptual stage of the project different span arrangements and structure types were evaluated for each bridge. Due to right-of-way limitations, long retaining walls were necessary at several locations. Therefore, limiting the total superstructure depth was very important in order to keep the profile low. For Route 17 crossing over Route 4 and the connector bridge over Route 4, a comparative study indicated that a two-span continuous steel superstructure would provide a shallower depth than prestressed concrete. For the curved ramp structures, a continuous steel superstructure with curved girders integral with the pier cap for the pier on Route 17 provided the most economical type of structure. For redundancy, a multi-girder superstructure was chosen. For economy of details and ease and speed of fabrication/construction, the steel fabricating industry was consulted during the preliminary and final design phases.

RAMP STRUCTURAL ANALYSIS

Due to the complex geometry and the presence of integral piers, a tested and reliable computer program was required for analysis and design. The ramp bridges were analyzed and designed using a three-dimensional, finite element program developed by BSDI, Ltd. The program allows a detailed analysis at various stages, including construction condition, e.g., girder erection stage and effects on the superstructure prior to placing the concrete deck, effects of placing the deck for specified sequences of concrete placement, and also if the deck concrete were to be placed all at once. The effects of thermal loading were also included as a separate load condition.

The analysis included the stiffness of the deck slab and the entire superstructure was analyzed as a total system, including the deck, girders, cross frames, and bearings. From the input data supplied, the program creates finite-element models considering non-composite and composite structural behavior. Girder flanges were modeled with beam elements, webs using shell elements, and cross frames were modeled using truss elements. The deck slab was modeled using eight-node solid elements and connected to the girder top flange with beam elements for the shear studs. For the design in negative moment regions, as mandated by NJDOT, the contribution of the deck reinforcement steel was ignored; however for live load and superimposed dead load distribution, the composite action was included.

For the integral fixed pier, a special analysis was performed where the model included the pier as an integral part of the superstructure. The pier column was modeled to a "point of fixity". Thus the model recognized the effect of pier stiffness on the superstructure.

HS25 was the specified live loading for design. Maximum and minimum responses for the moments, shears and torques were included in the analysis output.

Girder design was an iterative, interactive procedure performed using the responses stored at each nodal point. Curve fitting techniques were utilized internally by the program to check responses at any intermediate point along the girder. For each point checked, a constructability check was performed to check for lateral flange stability.

The program included the effect of different stiffnesses of girder sections for successive pours. For this scenario, top of deck stresses of staged deck placement were carefully reviewed to avoid tensile cracks during subsequent deck placement.

Ramp SE/Ramp NW: The design was performed using the AASHTO Guide Specifications for Horizontally Curved Bridges. Allowable Stress Design, then mandated by NJDOT (currently NJDOT utilizes LRFD methodology) was used.

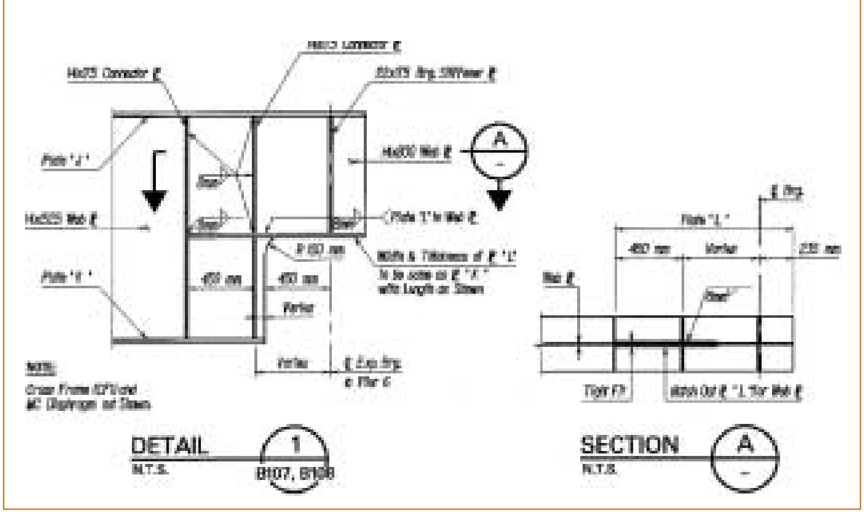
All the structural steel for the girders, bearings, and bearing stiffeners was specified to be Grade 50, while Grade 36 steel was used for cross frames and connection plates. For economy of fabrication, the web plates were specified to be of the same thickness throughout, with no intermediate stiffeners. An evaluation of reducing web plate thickness using transverse intermediate stiffeners favored the former option, since the reduction in material costs would be offset by the additional cost of welding and testing.

The total length of curved girders for the two ramps is 2,377.5 m (7800 feet) (1280.2 m (4200 feet) at Ramp SE, 1,097.3 m(3600 feet) at Ramp NW). For economy of fabrication of the flange plates, a minimal number of plate thicknesses were specified. Since the flange plates had to be cut individually due to the different curvature on each, by using the same thickness and varying the flange widths from girder to girder line within the span, only five different flange plate thicknesses were sufficient for both of the ramp bridges.

The girders typically utilized fillet welds throughout. If the fabricator required flange or web plate shop welds, full penetration butt welds (B-L2C-S or B-U3C-S) were specified. However, for the plate thickness and lengths shown on the plans it was verified during the design phase that the lengths were readily available. No butt-welded shop splices were submitted by the fabricator.

For further economy, locations of the field splices were slightly adjusted from their theoretical locations (at or near dead load contraflexure) so that the lengths of as many plates as possible could be the same or nearly so within any span, in order to minimize waste during cutting of the individual flanges. Extending the thicker plate from the piers to the adjacent field splice in the span was slightly cheaper at almost all locations than introducing a flange thickness transition with a shop butt weld. Therefore, for overall economy and speed of fabrication, the change in flange plate thickness was always achieved at the field splice location.

Although the flange plate widths varied, the field splice plate thicknesses and widths were kept the same at all locations for economy of fabrication. At the few locations where a change was necessary, only the splice plate length was changed. All interior cross frames were detailed identical for repetitious fabrication. K-frame cross frames were typically used at all locations, and slightly modified to support the deck joints. No fatigue detail greater than Category C was specified anywhere on the superstructure and a careful consideration during shop drawing review



Detail of dapped girder end, necessary due to vertical clearance requirements.

phase resulted in no detail exceeding Category C.

Dead load camber and primary moments and shears were listed at every tenth point along each girder. To extract and customize the required values from the output of the design software, spreadsheets were developed in-house.

CONSTRUCTION PHASE

The construction phase began with the opening of the bid documents by NJDOT on September 10, 1998. Working in a congested area required the contractor to devote special attention to the maintenance of traffic and to community awareness due to the high impact on traffic flow. Six bids were received, ranging from $49.7 million to $72.6 million. The engineer's estimate for the project was $61.6 million, which included 10% for contingencies.

Total structural steel quantities of Grade 36 was 298,000 lb for curved girders ($0.84/lb) and 112,000 lb for straight girders ($0.98/lb). The total quantity of Grade 50 steel was 2,600,000 at the curved ramps ($1.06/lb), and 1,716,000 lb at straight bridges ($0.97/lb).

The first shop drawings and requests for information were received in early October, 1998. NJDOT had significantly reduced their preliminary estimated construction schedule of 54 months to only 30 months by the time the bid documents were opened by changing several sequential construction activities to overlapping ones and by implementing a thorough constructability review. To further reduce the schedule, they offered the contractor a $3.5 million bonus if the 30-month schedule could be reduced to 23 months. After only four months of work the contractor felt confident enough to request that a second bonus be given if they were able to cut one more year from the schedule. An agreement was reached for another $3.5 million incentive bonus for completion by November 23, 1999. The contractor was able to accomplish this goal, which compressed the original construction schedule of 30 months down to only 13 months. These changes to the construction schedule required the design team to accelerate their review of the shop-requiring long hours to keep pace with the contractor's construction activities.

STEEL ERECTION

The erection of the structural steel for the curved viaducts required careful planning and close coordination. Several girder picks had to be made during overnight off-peak hours due to traffic considerations. Several large cranes were required.

In general, most of the field sections for the steel were pre-assembled on the ground in pairs. Ground splices were blocked and fully torqued in accordance with slip critical criteria. The contractor chose to not fully tighten the diaphragm connection bolts on the ground so as to allow additional tolerance during erection. Since the entire superstructure was modeled as a unit, the contractor was required to survey the top of girder elevations after steel erection for conformance with theoretical values.

CONCLUSION

This complex project was completed well ahead of the estimated schedule through a team effort on the part of the contractor, design team, and the owner, resulting in a very satisfied and happy motoring public. A significant relief to the peak-hour volume of traffic has occurred, and the numerous business owners in the shopping malls have also benefited. Although the contractor bid the project at cost, he gained a significant incentive bonus of $7 million (approximately 15% of his bid cost), while the owner was very happy to see the project completed so far ahead of schedule.

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OWNER
New Jersey Department of Transportation

STRUCTURAL ENGINEER
Parsons-Brinckerhoff, Princeton, NJ

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

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

GENERAL CONTRACTOR
Joint venture:
Bishop-Sanzari, White Plains, NY and Fletcher Creamer Inc., Hackensack, NJ

ENGINEERING SOFTWARE
BSDI 3D System