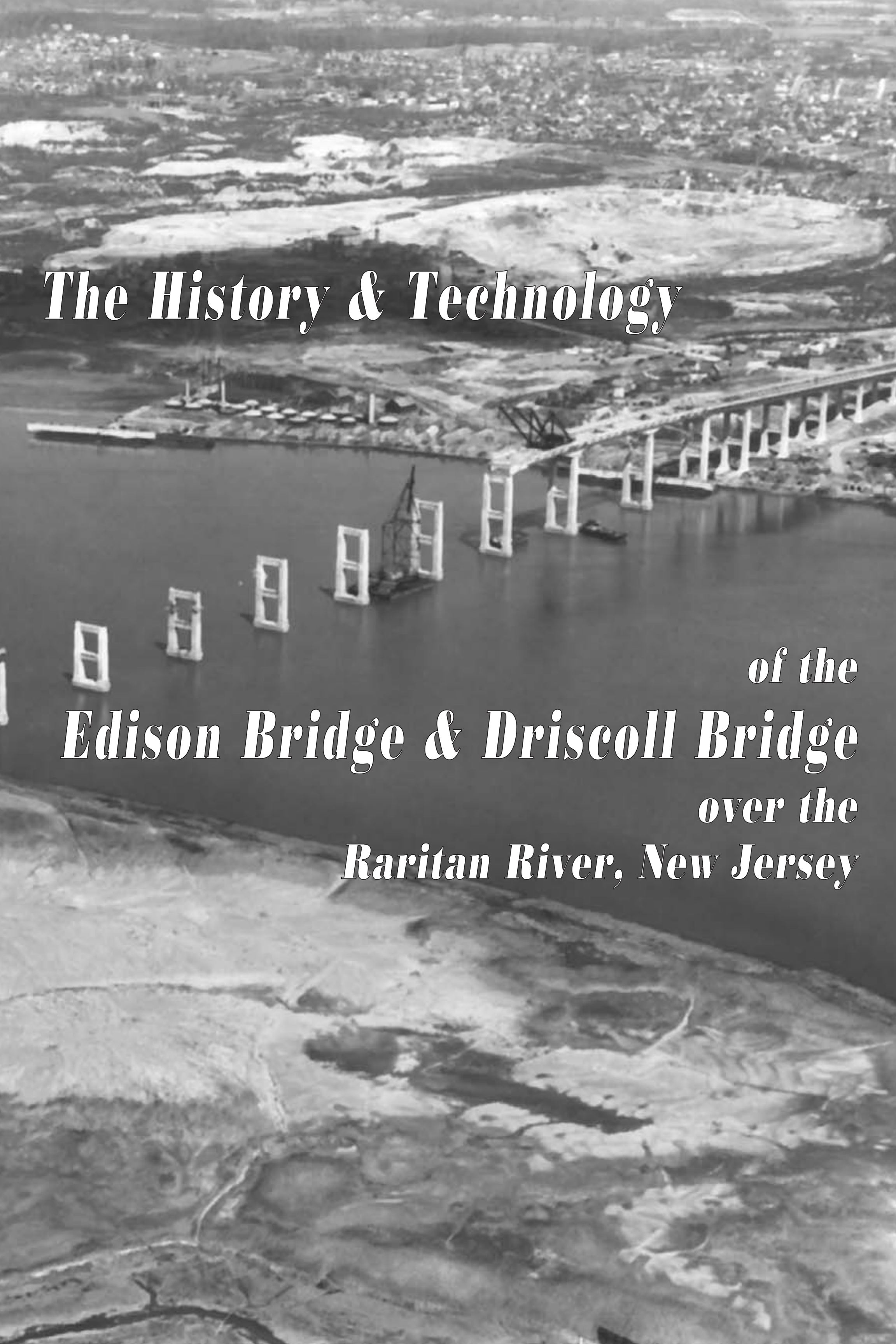

The History & Technology

of the Edison Bridge & Driscoll Bridge over the Raritan River, New Jersey

Construction of the Edison Bridge, 1940.
Source: New Jersey Department of Transportation.

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Edison Bridge & Driscoll Bridge

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Printed in the United States of America.

This document was written by Richard M. Casella and Julius Haas, and edited and produced by Susan D. Grzybowski, C. Carol Halitsky, and Hope E. Luhman of THE Louis Berger Group, INC., East Orange, New Jersey.

INTRODUCTION

The Route 9 Edison Bridge and Garden State Parkway Driscoll Bridge cross the Raritan River together to form one of New Jersey's most vital highway links. Barring accidents or construction, as many as 275,000 vehicles per day cross these two bridges, making them perhaps the heaviest traveled twin bridges in the world.

The route across the Raritan between Perth Amboy and South Amboy has been important since the state's earliest days. In 1684, Radford's Ferry provided the link for the stagecoach line between New York and Philadelphia. For over 200 years, ferries shuttled travelers across the Raritan.

In 1875, Perth Amboy and South Amboy were joined by a bridge for the first time with the construction of the New York and Long Branch Railroad Bridge across the mouth of the Raritan River. The line ran from Long Branch to Perth Amboy, where it made connections with branches of the Pennsylvania and the Central New Jersey railroads. This new line was instrumental in the further development of seaside resorts along the Jersey shore in Monmouth and Ocean counties and was soon transporting hordes of summer beachgoers.

Victory Bridge, in foreground, is a swing bridge, pivoting on a center pier to allow boat traffic to pass through two channels. Opening the bridge in the summer resulted in huge traffic backups. Edison Bridge, west of the Victory, was built high enough to allow all vessels to pass under. Source: NJDOT

The railroad bridge stalled the construction of a highway bridge over the mouth of the Raritan River until 1910, when a "county bridge" was erected with a drawspan in the middle. Within a few years, it was inadequate to handle the traffic and the weight of increasingly larger trucks. Calls for a new bridge, which began in 1916, were answered ten years later by the Victory Bridge.

Again the anticipated traffic loads were grossly underestimated. No one could have predicted that the number of car registrations in the United States would triple during the 1920s to 23 million. The Roaring Twenties might well have been named for the sound of overheated cars and drivers heading to the Jersey beaches over the Victory Bridge on a typical summer weekend. Hordes of new car owners had discovered the joy of motoring to the beaches. To make matters worse, the increase in pleasure boating, also on the weekends, led to more frequent openings of the Victory Bridge. It was apparent to the locals that a second bridge, not a replacement, was required, and that it must be a fixed bridge, high enough for any conceivable vessel to pass freely under.

Beach traffic on the Victory Bridge–visible in the background–in the late 1930s. Source: NJDOT

THE EDISON BRIDGE

The Edison Bridge was the centerpiece of a limited-access highway around downtown Perth Amboy, officially referred to as "Route 35 Extension from the Woodbridge Cloverleaf to Keyport," but known to most as the Perth Amboy Bypass. The roadwork began in 1935 with the re-routing of Route 35 and Route 4 from Victory Bridge into a new traffic circle in South Amboy. In August, 1938, the state legislature approved $4 million in funding for the bridge project, and officially named it the Thomas A. Edison Bridge. A Federal grant from the Public Works Administration covered 45 percent of the total cost.

Source: NJDOT

The design of the Edison Bridge was the direct responsibility of Morris Goodkind, chief engineer of the bridge division of the New Jersey State Highway Department, a position he had held since 1925. Goodkind had a well-established national reputation. Two of his monumental bridge projects, College Bridge, carrying U.S. Route 1 over the Raritan River and built in 1929, and the Pulaski Skyway, a high-level viaduct and bridge system over the Passaic and Hackensack rivers, completed in 1932, had earned international attention (see article below on Morris Goodkind). Goodkind oversaw the preparation of plans and drawings for the bridge by his staff, most notably bridge designer W.F. Hunter and chief draftsman, L.C. Petersen. The engineering firm of Ash, Howard, Needles and Tammen of New York City consulted on the design and reviewed the plans.

The location chosen for the new highway and bridge was 3,000 feet to the west of the Victory Bridge. The federal requirement of a minimum of 135' of clearance under the bridge for navigation meant that long approaches would be required to keep the road grade within acceptable limits. In a bold move, Goodkind and his engineering team agreed on a design calling for the longest and heaviest *deck* plate-girder highway bridge ever built in the United States. The deck girder bridge type had become the first choice of engineers for long-span highway bridges owing to its economy, ease of construction, and other practical features (see article below on bridge technology).

The final design called for a bridge with 29 spans and an overall length of 4,391 feet. The nine spans over the river would consist of three *continuous* span girders of record-setting proportions. The main girder over the navigation channel would be 650' in length, consisting of a 250' span flanked by two 200' spans, and would set a new U.S. record for length. The two other continuous girders were each 600' in length, consisting of three 200' spans. The unprecedented design posed unique problems and challenges to the bridge builders. As firms specialize in different aspects of construction, and the engineers wanted to ensure the most competition and lowest price for the bridge, the project was divided into six separate contracts: the river piers, the river pier shafts, the south approach piers, the north approach piers, structural steel, and the concrete deck and lighting systems. The most complicated and expensive parts of the project were the river piers and the structural steel.

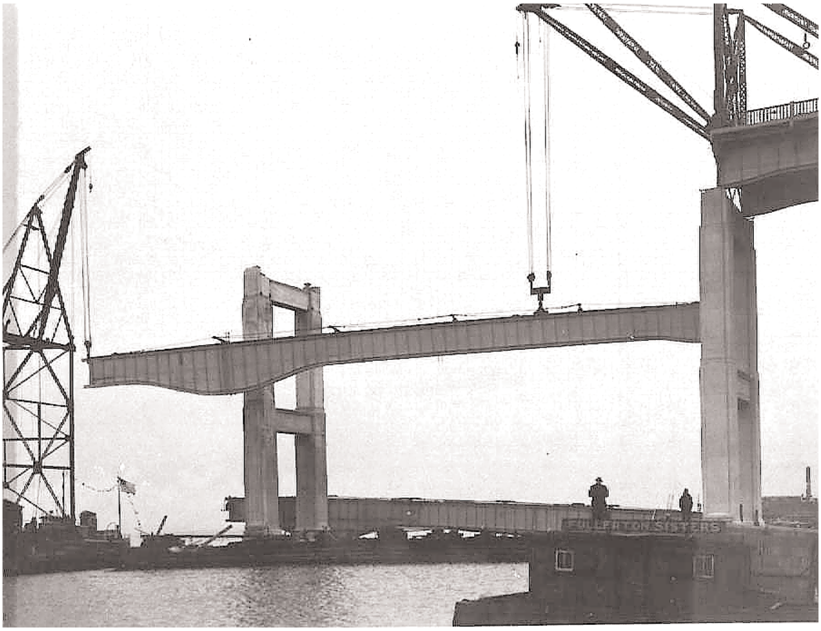
The Peter F. Connolly Company won the two contracts for the river piers and shafts and began work on September 26, 1938. The massive amount of concrete required for the huge piers to support the bridge at such a great height over the river called for special equipment and techniques that Connolly developed (see photo caption). The contracts for the north and south approach piers, which were relatively straightforward to construct, were won by the J.F. Chapman Company and the Folhaber Pile Company, respectively. The concrete deck and lighting contract was awarded to the John G. English and Joseph Nesto Company.

Construction of the ten massive concrete river piers and shafts required special floating equipment, designed and built for the job by the contractor, the Peter F. Connolly Company. A floating derrick was modified to reach 150' to the top of the piers. Cement was delivered by rail to a waterside track where a separate derrick boat transferred it to a floating barge. A screw conveyor and bucket elevator transferred the cement to a floating concrete plant, which mixed the batches and discharged the wet concrete onto a system of belt conveyors. Connolly also developed a novel method for preassembling the steel reinforcing for the pier shaft inside formwork that was then lifted into place by a tall crane. The contractor's work was featured in an article entitled "Unusual Equipment Speeds Caissons and Piers", which appeared in Engineering News Record magazine. Source: NJDOT

Far more challenging was the job of fabricating and erecting the structural steel for the bridge. The only bridge builders capable of the job were divisions of the nation's two largest steel manufacturers: American Bridge Company, a part of U.S. Steel Corporation, and Bethlehem Steel Company's Fabricated Steel Construction Division. Bethlehem won the contract and built the steelwork in their Pottstown, Pennsylvania, plant.

The fabrication, shipment, final assembly, and erection of the bridge girders involved many unusual problems because of their unprecedented weight, length, and depth. Special railcars were built for the haul from the factory to Jersey City, and even then the massive girders cleared the rail by only 4" and the overhead power lines by only 5". For safety, the electricity was shut down, and a diesel locomotive was utilized. At Jersey City, the girders were loaded on *car float barges* for delivery by water to the bridge site.

The 600' and 650' continuous girders built to span the river were completely assembled at the plant and then disassembled into seven pieces to enable shipment by rail. The pieces were then *field spliced* at the construction site to form three huge sections, the largest of which was 260' in length and weighed 198 tons, a world record. Mr. C.L. Lane, assistant manager of erection for Bethlehem Steel Company, supervised the erection of the *superstructure*, which began on September 1, 1939, and took slightly over 14 months to complete.



Lifting the main girders in place set a new heavy-lift record in the U.S. The final cost of the bridge was $4,696,000. More than 65,000 cubic yards of masonry, 50 percent buried from sight, went into the foundations, piers, and deck of the bridge. Over 2,500,000 pounds of reinforcing steel and 19,000,000 pounds of structural steel were used. Source: NJDOT

The first step in erecting the steelwork was the setting of the *simple span* girders for the approaches. This work was accomplished simultaneously from both ends using a combination of land cranes and traveling cranes, called travelers, which rolled on rails mounted directly on the girders. As each pair of girders was placed, the rails were extended, and the traveler moved forward toward the river. The larger of the two travelers had a capacity of 125 tons, was powered by a 300-horsepower engine, and weighed 260 tons. The north approach consisted of six 85' spans and six 155' spans, while the south approach consisted of eight 135' spans.

The erection of the 260' long, 200-ton sections of the river spans required the design and construction of one of the world's largest floating bridge-erection derricks. The floating derrick was assisted in lifting the river spans by the 125-ton capacity traveler. To prevent bending in the girder during the lift, a horizontal stiffening *truss* was attached to the girder and remained in place until the girder pairs were joined together with floor beams.

The 260' girders could not be lifted into place if there was the slightest wind, and bad weather resulted in numerous delays. The first girder was successfully lifted into place on the morning of March 14, 1940, establishing the new heavy-lift record. The bracing system functioned perfectly. Several hours later, during the lift of the second girder, its bracing system failed, and the top *flange* buckled approximately three feet out of alignment. The girder was lowered to the barge and used again after it was straightened and determined suitable for use.

Upon completion of the steelwork, the concrete deck was laid, and railings and lighting were installed. On November 20, 1940, the bridge was permanently opened to traffic. During the course of construction, three workers were killed in falls from the bridge.

The Edison Bridge was dedicated Saturday December 14, 1940. The ribbon was cut by Mrs. Mina Edison Hughes, widow of the inventor, shown above with State Senator John E. Toolan, Governor A. Harry Moore, and Governor-elect Charles Edison, son of the inventor, and Morris Goodkind. Roughly 1,150 people, including a detachment of 650 soldiers from Fort Dix, attended the dedication. State Highway Commissioner E. Donald Sterner declared that the bridge, situated in a state where one-third of the nation's key industries were located, was a vital link in the national defense program. Source: NJDOT

THE DRISCOLL BRIDGE

The creation of the New Jersey Highway Authority in 1952 included a mandate to construct the Garden State Parkway as quickly as possible to relieve the increasing traffic congestion in New Jersey. A centerpiece of the project was the bridge carrying the Parkway over the Raritan River at Perth Amboy. Named for Alfred E. Driscoll, New Jersey Governor from 1947 to 1954, it is the largest of the Parkway's nearly 300 bridges, and one of the state's busiest, carrying an average of over 200,000 vehicles per day.

The Driscoll Bridge was designed as a nearly identical twin of the Edison Bridge because of the channel clearance requirements set forth by the U.S. Department of the Army. With jurisdiction to determine the minimum height and width of bridges over navigable waterways, the U.S. Army Corps of Engineers required that the 135' height and 250' channel span specified for the Edison Bridge fourteen years earlier would also apply to the Driscoll Bridge. A further condition, that the channel piers of both bridges share a common fender system, resulted in the new bridge being located just 175 feet west of the Edison Bridge. This ensured that navigation and river currents would not be impeded by an excessively long fendered channel or by a second restricted channel a short distance away.

Whatever difficulties these requirements posed for the Parkway's planners were offset by benefits to the bridge engineers. With the bridges so close together, it was logical for both aesthetic and practical reasons that they be twins with essentially the same engineering and architectural features. The highly successful and record-setting Edison Bridge provided a full-scale model with plans and records from which the details of design, fabrication, erection, and cost of the new bridge could all be extrapolated.

The design and construction oversight of the Driscoll Bridge was the result of a collaboration between three groups of engineers: the New Jersey Highway Authority staff, the consultants to the Authority for the overall Garden State Parkway project, and the bridge design firm of D.B. Steinman of New York City.

Harold W. Griffin, chief engineer of the New Jersey Highway Authority, carried overall responsibility for the Driscoll Bridge project and was assisted by Harry A. Hartman, supervisor of construction. The firm of Parsons, Brinkerhoff, Hall & McDonald served as general consultants for the Parkway project, and Morris Goodkind served as consulting bridge engineer for the Parkway's bridges. Goodkind was chief bridge engineer at the New Jersey State Highway Department at the time and had been responsible for the design of the Edison Bridge fourteen years earlier.

David B. Steinman was one of the world's leading bridge engineers at the time and was chosen for his particular experience with long-span *plate-girder* bridges. Steinman and his partner, Holton D. Robinson, pushed the limits of bridge materials and engineering, and designed many of the early record-setting suspension bridges during the 1920s and 1930s. The firm of Robinson and Steinman had designed the Charter Oak Bridge at Hartford, Connecticut, completed in 1942, which held the title as longest plate-girder bridge in the United States until 1951, when the twin New Jersey turnpike bridges over the Passaic and Hackensack rivers were completed.

The Garden State Parkway

Construction of the Garden State Parkway (GSP) began in 1946 after passage of New Jersey's Parkway and Freeway Act. The GSP was started as part of the state highway system and was initially funded with annual highway appropriations. By 1950, with only ten miles of the parkway's 165-mile route opened, it became apparent that with only annual appropriations, the project might take 40 years to complete.

In April 1952, the legislature created the New Jersey Highway Authority to build, maintain, and administer the GSP using state-backed bonds to be paid back with tolls. When voters overwhelmingly approved the project referendum in the November election, the Authority began construction on a large scale. By the end of 1953, $140 million in construction contracts had been awarded, and the construction of 177 of the GSP's 282 bridges was proceeding rapidly along.

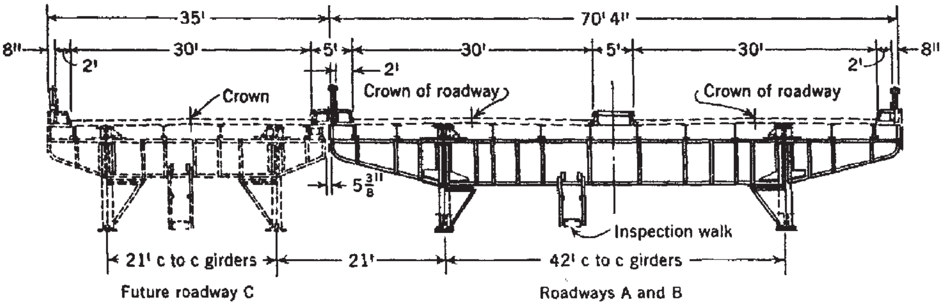
The 165-mile-long parkway was designed to connect the northern metropolitan areas and southern coastal areas. With more than 200 entrance and exit ramps, it would lessen congestion on local roads along the way. The GSP was built to move New Jersey drivers around their state, in contrast to the Turnpike, which was built with very few exits, and channeled interstate traffic in one end and out the other.

In addition to the 13 engineers on staff, the Highway Authority assembled a team of 24 of New Jersey's leading engineering consultants and firms. The engineers employed state-of-the-art highway and bridge planning and design technology. Features to accommodate future traffic needs were "built-in," such as banked curves to safely handle speeds up to 70 miles per hour, and wide medians and shoulders for additional travel lanes. Extra concrete foundations were even added to allow for bridges to be widened. This feature saved taxpayers several million dollars when the bridge was widened in 1972.

The Raritan River Bridge was finished three months ahead of schedule in July 1954, and the GSP, being largely completed, was officially opened on October 23, 1954, by Governor Meyner. In May 1956, with the opening of the Great Egg Harbor Bridge, the parkway was complete. The nine-mile extension joining the GSP to the New York State Thruway was added in 1957. The Raritan River Bridge has since been renamed after Alfred E. Driscoll, governor of New Jersey from 1947 to 1953.

The robust economy and suburban housing boom that followed World War II resulted in not just one car in every garage, but two, and a multitude of new trucks for every commercial purpose.

Nowhere was the impact of all these vehicles felt more than on New Jersey's highways. But New Jersey's drivers were long acquainted with traffic jams, dating from the early days of the automobile when beach traffic backed up in legendary proportions. Geographically positioned as New England's gateway, the Garden State also suffered from large and ever-increasing numbers of interstate travelers and commerce just passing through. To many it seemed that traffic could only get worse. And so, in the early 1950s, with the good times rolling, taxpayers embraced heavy investment in highways that would carry them far into the future. New Jersey was ready to lead the way, and the Garden State Parkway would be a standard bearer.



Driscoll Bridge Evolution. *The bridge was originally built with two 30' concrete roadways, a 5' center mall, and two 2' emergency walkways to accommodate four 15' wide lanes of traffic. In 1957, the deck was re-striped to accommodate six 10' lanes. Between 1970 and 1972, a third set of columns was added, resting on the foundations built for them in 1955, and the superstructure was widened from six lanes to ten lanes. In 1984, the timber median barrier was replaced with a concrete barrier to provide six lanes of traffic in each direction. Source: Gronquist 1955.*

With no opportunity for record setting, the Driscoll Bridge project was essentially a "bread-and-butter job" for Dr. Steinman. As part of a major new high-capacity highway system, it did, however, call for the best practice in design, materials, and construction to ensure long, efficient service. Notable in this regard were special structural features to allow economical widening of the bridge to meet future traffic demands, and a state-of-the-art concrete deck. Building bridges has always been one of the most expensive public undertakings. Although the great initial cost justifies some additional expenses to ensure long life, the public generally cannot accept expensive over-designing for estimated future traffic loads. Bridges are normally bottlenecks because they cannot be economically equipped with wide shoulders and breakdown lanes needed for maximum traffic flow. It was therefore considered significant at the time that not only was the Driscoll Bridge designed with unusually wide travel lanes and broad shoulders, but that a major investment was made in building extra foundations for a third roadway to be built sometime in the future.

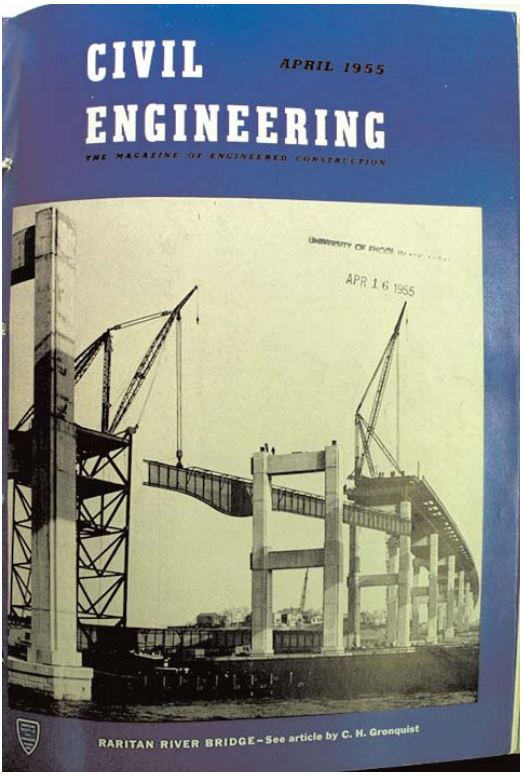
The second special feature of the Driscoll Bridge was the design of the concrete deck, which provided for the latest advances in construction methods and equipment. Efficient techniques developed three years earlier for building the decks of the huge New Jersey Turnpike bridges over the Passaic and Hackensack rivers were studied and incorporated into the design of the Driscoll Bridge. The attributes of good engineering– great speed, high quality, and economy–had all been achieved.

In designing the 7" thick concrete deck for the Driscoll Bridge, the engineers started with the specifications used by the New Jersey State Highway Department and then turned their efforts to achieving the smoothest possible riding surface. The use of structural-steel continuous-drain curbs, and steel grating for the sidewalks and center mall, simplified the concrete work. The walks provided workers easy access for construction of the bridge deck. The curbs served as a fixed support and guide on which to slide the deck *screed* and personnel bridges that were used in spreading and smoothing the wet concrete.

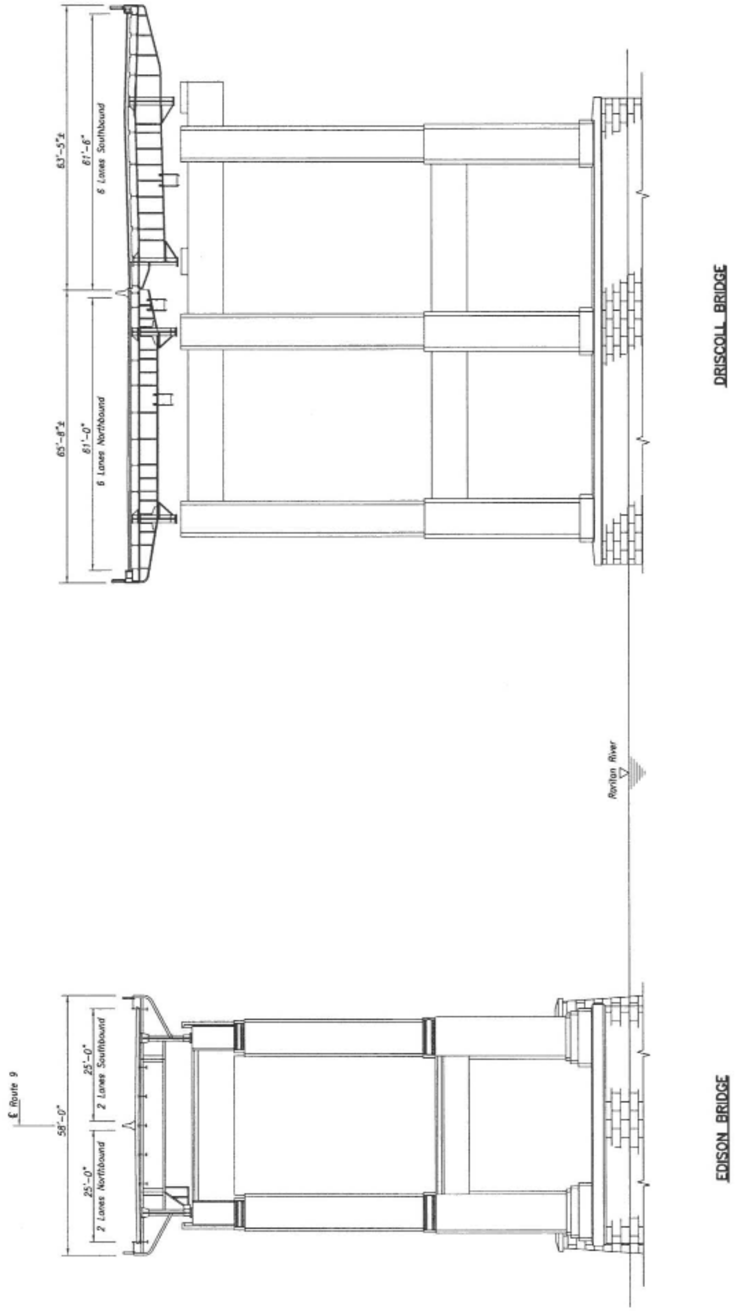
The steel curbs were set in place with precision and closely inspected by the field engineers for uniformity. The finishing of the concrete deck required several steps: a vibrating screed, mounted on wheels that rode on the curbing, was pulled over the fresh concrete. This was followed by a wood float and then a straight-edge scraper, operated by two men from a pair of rolling bridges spanning the fresh pavement. Wet burlap cloth was then pulled across the surface, and the final finish was produced with a stiff bristle broom. The result was a nearly mile-long concrete surface that was considered as perfect as could be constructed.

The superstructure of the Driscoll Bridge was fabricated and erected by the Bethlehem Steel Company, the same contractor that built the Edison Bridge. As the Driscoll Bridge was a structural copy of the Edison Bridge, Bethlehem Steel had the necessary patterns for duplicating the girders and the equipment and experience for efficiently erecting the bridge. The construction process was essentially the same: the girders were assembled in the company's Pottstown, Pennsylvania, plant, transported by special railcars and barges to the site, and lifted with enormous cranes into place.

One improvement in the construction process was in the temporary stiffening truss attached to the girders to prevent lateral buckling during lifting and setting. During the lifting of the main girder for the Edison Bridge, the heaviest lift in the world at the time, the girder buckled slightly. The improved stiffening truss used high-strength bolts, torqued to a minimum tension of 25,600 lbs. The Driscoll Bridge was completed in July 1954, three months ahead of schedule.



Specially built to be easily widened to meet future traffic demands, the Driscoll Bridge was cited for its progressive design and was featured on the cover of the April 1955 Civil Engineering *magazine. Shown is the lifting of the massive 263' main girder, weighing over 200 tons, fabricated and erected by the Bethlehem Steel Company.*



GARDEN STATE PARKWAY AND ROUTE 9 BRIDGE
BEFORE WIDENING OF ROUTE 9

Historic Photos of Edison Bridge and Driscoll Bridge.

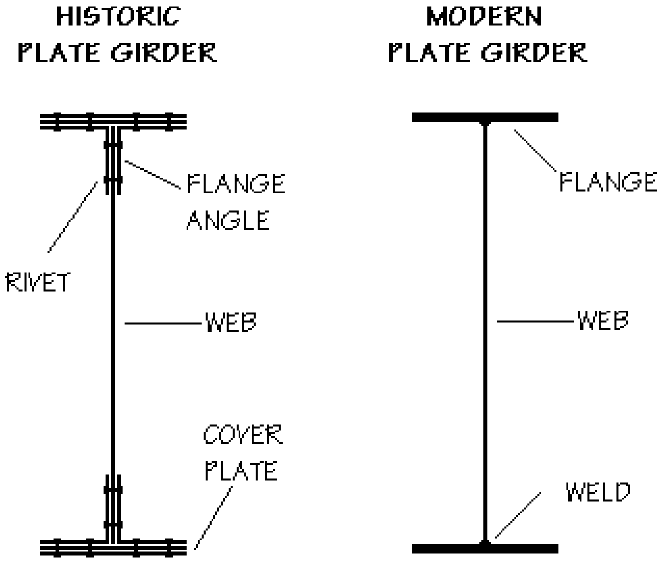
THE DESIGN AND TECHNOLOGY OF CONTINUOUS PLATE-GIRDER BRIDGES

The Edison and Driscoll bridges are continuous plate-girder deck bridges. The Edison Bridge is historically important as a large and early example of its type. It marked an important step in the development of the modern continuous plate-girder highway bridge in America, which began about 1932. The Driscoll Bridge, a duplicate of the Edison Bridge and built twelve years later, was significant for its special structural features that allowed the latest advances in construction methods and equipment to be used in laying its concrete deck and provided for the economical widening of the bridge at a later date to meet future traffic demands.

When completed, the Edison Bridge not only exceeded common engineering practice but set records in the United States for its type and for bridge building practice. It was the largest and highest girder bridge in the United States, and shared the record for longest girder span with a bridge in Charleston, West Virginia. (The Charleston Bridge was begun after the Edison Bridge, but was completed sooner owing to its much smaller overall size.) The placing of the main-span girders of the Edison Bridge on piers 135' above the Raritan River involved the lifting of the world's longest (260'), heaviest (198 tons), and deepest (20'-6") girder ever erected in the United States. Special train cars, barges, and cranes were constructed to transport and erect the girder.

The first plate-girder bridge in America was a simple-span structure of wrought-iron construction, erected for the Baltimore and Susquehanna Railroad. Plate girders were widely adopted by the railroads for spans of up to 100', and by the early 20th century, constituted all but a small percentage of short span railroad bridges. Although less efficient in terms of materials, railroads preferred plate girders to trusses for numerous reasons: simple design and durability; ease of construction, shipment, and erection; higher mass and rigidity and therefore less sensitivity to vibration; and suitability for use in positions of small clearance. Railroads had the means to ship the girders in one piece and derrick cars for lifting and setting the girders in place.

A continuous beam (or girder) is a solid beam supported at three or more points along its length and designed to carry a greater load than a *simple beam* of the



Typically I-shaped in cross-section, a plate girder originally consisted of a rectangular steel plate (the web) riveted to parallel pairs of top and bottom angles (the flanges) to form a deeper beam than can be produced in a steel-rolling mill. Steel cover plates were joined to the top and bottom flanges, and vertical angles–called angle stiffeners–were joined to the web plates at regular intervals for additional strength. Advances in welding methods by the 1950s eliminated rivets. Without rivet holes, which reduced strength, a single, heavier plate could be used. Stiffeners are still used but consist of narrow plates welded in place.

same size and span. Trusses, plate girders, and box girders can all be made continuous. The structural advantage of a continuous beam over a simple span results from bending forces created in the beam over the piers, which counteract and reduce the bending forces in the center of the span. Among the practical advantages are economy of material, increased rigidity, and the convenience of erection without *falsework*. Fewer *bearings* and expansion joints and shorter approaches as a result of reduced girder depth are other desirable features. When continuous beams were first put into use, some engineers believed that there were structural advantages to making more than three spans continuous, but it was later proven that no increase in rigidity was obtained with more than three spans.

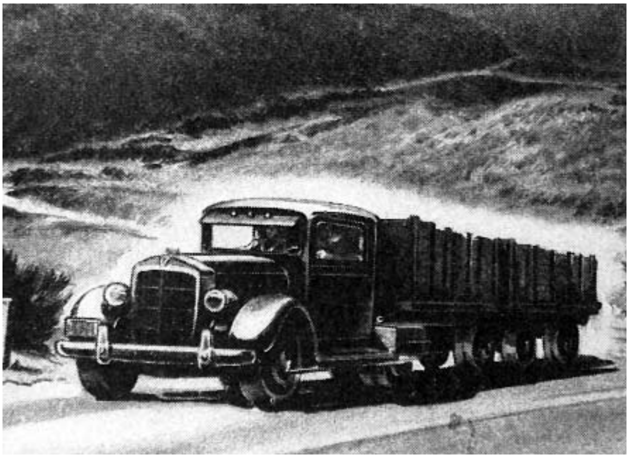
The continuous girder originated in Europe, with minor examples built for railroads in Germany, France, Switzerland, and Austria as early as 1835. The first large continuous bridge was the Britannia Bridge over the Menai Straits in England, built in 1848 by Robert Stevenson. It was a four-span tubular plate-girder (box-girder) bridge with two 460' and two 230' spans and carried railroad tracks through it. This remarkable bridge held the plate-girder record until the building of the 528' Frankenthal Bridge at Cologne, Germany, in 1939. Another long-span tubular iron railroad bridge was built by Stevenson over the St. Lawrence River at Montreal in 1854-1860, but it was so expensive that the design was never adopted by American engineers.

From the late 19th century through the 20th century, continuous girders were used by American railroads for short-span bridges, viaducts, and elevated lines and widely applied in steel-frame building construction. Plate girders were rarely used for highway bridges: they were too difficult to haul over country roads, and even the lightest designs greatly exceeded the strength necessary to carry the small *live loads* of early road vehicles. Even the railroads could not readily transport and handle plate girders in one piece much beyond 100' in length.

Trusses on the other hand were much lighter, used less steel than a plate girder for a given span, and could be assembled at the plant and disassembled for shipment. The first continuous truss bridge in the United States was a double-track railroad bridge spanning the Ohio River at Sciotoville, built by Gustav Lindenthal in 1917. The twin 775' spans of the bridge shattered the previous world record of 472' for a continuous truss bridge.

As the nation's roads and highways were improved and extended during the teens and twenties to meet the exploding population of motor vehicles, engineers first turned to inexpensive and easily erected concrete bridges or light *through* truss bridges. The Germans were the first to begin applying the continuous plate girder to long-span highway bridges, beginning in the early 1920s. They built a two-span continuous-girder bridge over the Neckar River at Mannheim in 1926 with spans of 282' and 180', a design that far exceeded anything Americans would build for nearly two decades. German engineers advanced plate-girder technology through the 1930s and 1940s, outdistancing the rest of the world in terms of number of bridges and length of span.

In the United States, it was not until the 1930s that a number of factors came together that led to the rapid development and adoption of the continuous plate-



Many bridges were replaced in the 1930s and 1940s to accommodate the new heavy trucks.

girder highway bridge. In 1929, Yale engineering professor Hardy Cross published his famous *moment distribution method* for the analysis of continuous frames and beams. At roughly the same time, mechanical and *photoelastic* methods for checking stresses in celluloid, metal, or glass models of complex *statically indeterminate* structures were developed. Models enabled designers to visualize the behavior of every part of the structure under various conditions of loading and correlate the observations to analytical results. As metallurgical research provided a better understanding of the elastic properties of steel, engineers overcome their fear of *reversal stresses* in continuous girders and a sharp increase in their application soon followed.

The *deck bridge* also became the preferred form for highway bridges during the 1930s as the speed and number of automobiles increased, and the advantages of the type became more apparent. As opposed to a *through bridge*, a deck bridge provides an unobstructed view, creates less anxiety in the motorist from feeling hemmed-in, and allows greater speed and safety because the optical illusion of a narrowing roadway is nearly eliminated.

Bridge engineers within state highway departments became the chief proponents of the continuous plate-girder deck bridge. The economic depression forced states to stretch their road budgets, and the new bridge type was proving to be the most economical solution for most elevated and medium-span highway bridge applications.

Articles appeared in engineering journals describing the successful use of continuous plate-girder bridges in Kansas, Georgia, Nebraska, and Montana. The Kansas highway department built over fifty continuous bridges between

1933 and 1935 and reported that the savings over simple span structures were estimated at between 10 and 30 percent, covering the increased engineering cost many times over. In addition to savings on steel, joints, and bearings, the greater rigidity of these bridges reduced deflections and allowed shallower concrete deck construction. More costs were shaved by reducing the size of the pier caps and eliminating some end floor beams. By the end of the decade, most state highway departments were on the bandwagon.

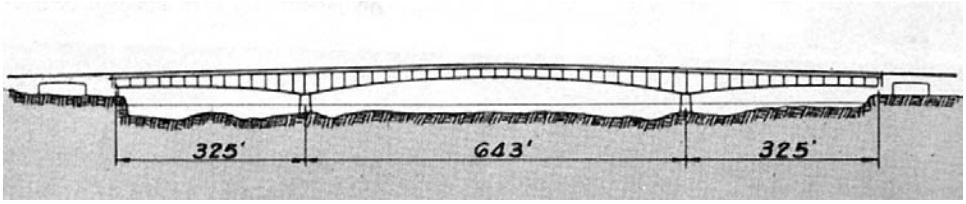
A landmark in the development of the modern long-span continuous plate-girder bridge in the United States was the construction of the Capital Memorial Bridge in Frankfort, Kentucky, by the State Department of Highways in 1937. The 200' main span was the longest of its type in the U.S., and with a depth of only 12' at the supports and 7' at mid-span, it approached the maximum theoretical slenderness ratio. Its gracefully curved bottom chords won it the "most beautiful bridge of the year award" in its class from the American Institute of Steel Construction. Although more expensive to fabricate, curved bottom chords decreased deflections on longer girder spans with the added benefit of a more pleasing appearance.

The year 1938 was another banner year for continuous plate-girder bridges in the U.S., marked by a series of records set and broken. A 217' span was completed at Topeka, Kansas, while work commenced on a 220' span at Tallulah Falls, Georgia, and 250' long spans at Charleston, West Virginia, and Perth Amboy, New Jersey. The editors of *Engineering News-Record* called plate girders the most notable development in steel bridge design for 1939, citing the Edison Bridge as "the first and only long high-level plate girder in the country with a layout which hardly would have been considered suitable for plate girders even a few years ago."

Although it shared the record for span length with the Charleston Bridge, the Edison Bridge was of monumental class (bridges over $1 million in cost) with extraordinary features. The 52' wide roadway accommodated five lanes of traffic. The Charleston Bridge was two lanes wide. The much larger *live* and *dead loads* required massively deep and heavy girders, which at 250' long and 21' deep over the supports, were the largest in the country.

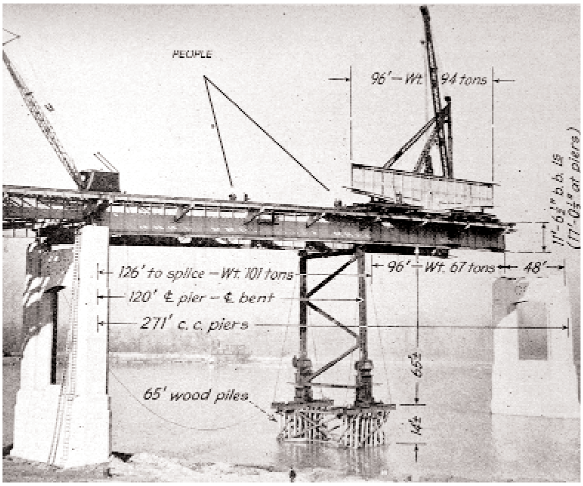
Just six months after completion of the Edison Bridge, a new span record of 271' was set by the Main Avenue Bridge in Cleveland. Although the bridge was also notable for its use of several all-welded rigid frames in the approaches, its camouflaged rockers, and the use of models to analyze the girder design, it did not approach the magnitude of the Edison Bridge.

Setting the next record came at a very high price. One of the worst accidents in bridge building history occurred during the erection of the Charter Oak Bridge over the Connecticut River at Hartford in 1941. Designed by the renowned bridge engineering firm of Robinson and Steinman, the 300' center span and 270' side spans formed a continuous girder, 840' in length. Temporary supports under the bridge collapsed during the erection of the center span. Thirty-two workers and engineers along with 470 tons of steel and a 176-ton traveling crane—the largest in the country—fell 100' into the river. Sixteen men were killed and the rest were critically injured. The engineering community focused on the ensuing investigation. When it was conclusively demonstrated that the cause of the accident lay in the erection methods used by the American Bridge Company and was not related to an "over bold design," construction quickly resumed. The bridge was completed as designed and opened without further incident.



The Bonn-Beuel Bridge over the Rhine River, 1949, with a center span of 643', was the longest continuous plate-girder bridge in the world at the time. The four girders, 36' deep at piers, were rigidly attached to the dished steel plate and concrete slab deck to form an early orthotropic design known as a tonnenbleche deck. Source: Troitsky 1968.

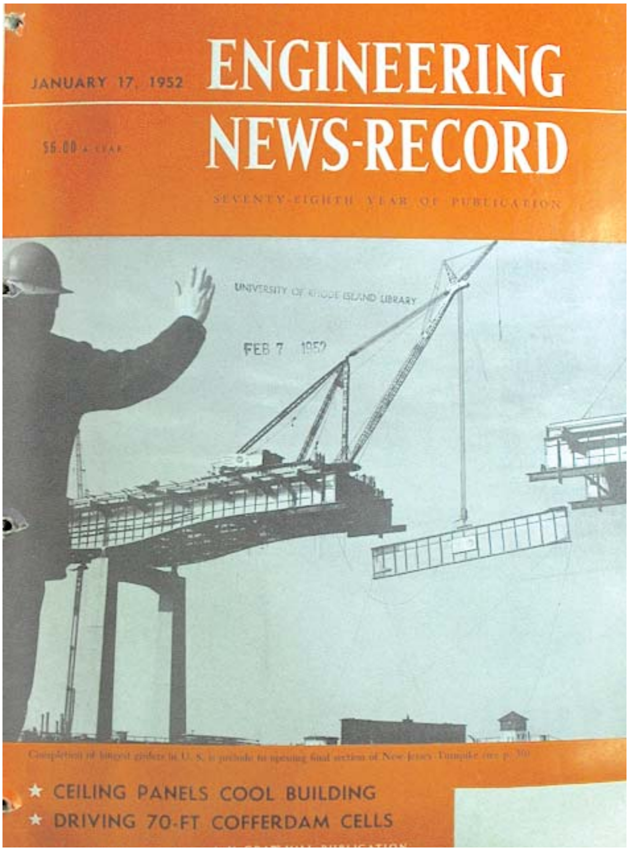
The onset of World War II brought a halt to bridge building in the United States, except for bridges deemed essential to the war effort. Ironically, the effects of the war would ultimately improve and speed the course of future bridge design here and abroad. The war destroyed more than 8,500 of Germany's bridges and left the world—especially Europe—with an enduring shortage of steel and other building materials. German engineers sharpened their pencils and quickly perfected theories proposed in the 1920s governing a type of bridge-deck design in which the steel girders and stringers of the superstructure were rigidly bonded to a continuous steel-plate floor. Building such "grid system" floors became possible with the development of welding. Eventually known as orthotropic bridges, these lightweight designs used less material and allowed far greater spans. By combining orthotropic deck designs and high-strength alloy steels, the Germans made huge leaps forward in continuous girder bridge technology. In 1948, the Cologne-Deutz Bridge established the new record with a 610' main span flanked by a 435' and a 396' span. Longer spans followed in rapid succession.



***Thirty-five Years Experience Not Enough**. Construction of Hartford Bridge, shown less than a minute before collapsing into the Connecticut River. In charge was W.J. (Jim) Ward, Erection Superintendent for American Bridge Company. Over his 35-year career, Ward erected many of this country's great bridges. Ward and 15 others died in the collapse, blamed on the temporary piles, visible in the photo, which snapped off below the mudline. Source: Engineering News-Record.*

Back in the United States, the war-induced structural steel shortage persisted into the 1950s, making modern reinforced concrete designs like *rigid-frames*, and *prestressed concrete*, a logical choice for short- to medium-span bridges. But steel prevailed for long spans, and as the post-war nation embarked on the building of thousands of new roads, parkways, turnpikes, and thruways, much of which became the interstate highway system, the plate girder was called back into service.

In 1952, the New Jersey Highway Department again led the nation by building two record-setting continuous plate-girder bridges, each with center spans of 375', for its huge New Jersey Turnpike project. The 375' span represented an increase of 25 percent over the Charter Oak Bridge, a large jump made more interesting by the fact it was accomplished by different engineers using different methods for each bridge. Ammann & Whitney, engineers of the Passaic River Bridge, followed accepted American practice specified by the American Association of State Highway Officials (AASHO). The engineers of the Hackensack Bridge, Howards, Needles, Tammen & Bergendoff, adopted the European practice of placing more of the required flange area in the cover plates, in this case 77 percent, which represented a substantial increase over the 60 percent specified by AASHO. New Jersey was back in bridge engineering headlines in 1954 with the building of the Driscoll Bridge, the longest bridge on the new state-of-the-art Garden State Parkway. Connecticut and D.B. Steinman, however, did not rest. In 1958, the country's most prominent practicing engineer once again took the title for the longest continuous plate-girder bridge in America back to the Nutmeg State. Just 12' longer than the twin New Jersey Turnpike spans, the Q-Bridge, as it became known, carries the Connecticut Turnpike over the Quinnipiac River at New Haven.



***New Jersey Recaptures Plate-Girder Record**. The New Jersey Turnpike bridges over the Passaic and Hackensack rivers were built as twins–not identical–but each with a main span of 375'. It was a new record for a continuous plate-girder bridge in the U.S. and in the case of the Hackensack span, it marked the adoption of more progressive European plate-girder bridge designs. The placing of the last section of the center span of the Hackensack Bridge is shown above on the cover of the January 17, 1952 issue of* Engineering News-Record.

German engineers, however, had already advanced plate-girder technology way beyond the Q-Bridge with the completion in 1956 of the Save River Bridge in Belgrade, Yugoslavia, a three-span continuous orthotropic design with a main span of 856'. This record stood until 1972 when the Rio-Niteroi Bridge over Guanabara Bay, Brazil, was opened. With a center span of 984' and an overall length of 45,604' (over 8 miles), the Niteroi Bridge remains the longest continuous plate-girder bridge in the world.

PLATE-GIRDER BRIDGE AESTHETICS

The importance of building beautiful or at least aesthetically pleasing bridges has been promoted since the Renaissance. Discussion of bridge aesthetics was limited to the characteristics of masonry arches erected throughout capitals of the world until the mid-19th century when new materials and methods were developed for heavy railroad bridges. The adoption of steel for bridge construction in the 1860s led to the building of huge truss and suspension bridges that were occasionally the subject of architectural criticism.

In America in the late 19th and early 20th centuries, the drastic need for bridges for rails and roads outweighed concerns about artistic design. To engineers and their paying customers, the bridge design that performed its intended purpose simply and with the least material and cost was the best design. Functionality, as engineers called it then, was considered pure and inherently beautiful in its own right, springing from the miracle of man's intelligence and his mastery of science and mathematics. Functionality combined with paternal pride to ensure that nearly every bridge, when opened and dedicated by its fathers and patrons, was declared beautiful.

And many of America's bridges were undeniably beautiful: the natural beauty of the arch and the catenary when rendered in steel had produced the Eads St. Louis Bridge and the Brooklyn Bridge, hailed as both engineering and architectural masterpieces. But the *architecture* of these bridges and the other great steel-arch, truss, and suspension bridges of the time was in the stonework of the towers, anchorages, piers, and *abutments*. The steel superstructure, on the other hand, was described by one critic as "a mathematical skeleton, sketched in with scanty steel along their lines of stress."

American bridge engineering treatises have included extensive sections on the aesthetic design of bridges since the late 19th century. Bridge designers were instructed to consider the fundamental principles of artistic design in the order of their importance: symmetry, style, form, dimensions, and ornamentation. Occasional commentaries on the elements of good aesthetic design and beauty as they pertained to bridges appeared in the engineering press in the early 20th century, but for the most part critics were kept busy disparaging the proliferation of new architectural styles and cheap machine-made building materials.

The first major schism in the philosophy of bridge architecture and aesthetics began in 1920 following a story in *Engineering News Record* about the ornately decorated Bensalem Avenue Bridge, built in Philadelphia. A nasty war was waged in a series of articles, editorials, and letters over the relationship between art and structures, between architects and engineers, and over who was more qualified to make such judgements.

Foremost among the causes of the dispute was the rapid development and adoption of reinforced concrete bridges for the nation's expanding highway network. Moldable into virtually any shape or form, economical, and well-suited to arches, concrete at first ushered in a nostalgic return to the classicism and heavy decoration found in earlier bridges crafted of stone. But a symbiotic relationship quickly developed between concrete and the new architecture of Modernism, promoted by Frank Lloyd Wright, Le Corbusier, Mies van der Rohe, and others. Functionality meshed with Machine Age philosophy to become Functionalism expressed in Modernistic concrete bridges. The traditionalists and the progressives were at each others throats.

Longing for the days of stone, renowned "old school" bridge engineer Gustav Lindenthal weighed in with an article in *Scientific American* in 1926 entitled "Some Aspects of Bridge Architecture." Dr. Lindenthal found fault with nearly everything that was happening in the bridge business but had special vehemence for the current art of steel bridge building: "there is no thought of architecture, or of durability or of pride in the art. . . the most naked utilitarian considerations are allowed to govern the design. . . it has become a commercialized trade which has been prostituted, under the pretense of scientific economy, to the production of the cheapest structures that will carry the loads."

Meanwhile, concrete bridge technology advanced, stretching bridges into long delicate arches or molding elements into highly stylized Classical, Art Deco, and Modern forms. Each year, increasingly stupendous and unarguably beautiful concrete bridges were going up. By 1929, the structural steel industry had had enough. The American Institute of Steel Construction (AISC) established an award to be given annually to the "most esthetic solution to a problem in steel construction." The first award went to the 6th Street Suspension Bridge in Pittsburgh, completed in 1928. In 1930, the AISC gave three awards based on a bridge's cost: Class A, over $1 million; Class B, $250,000-$1 million, and Class C, less than $250,000. The press coined the term "most beautiful steel bridge of the year award," which stuck.

Because of their ability to carry loads of massive weight and size, plate-girder bridges were used almost exclusively by the railroads up until the late 1920s. When used for highway bridges, the most common application was for railroad overpasses. Plate girders were easily delivered by rail and dropped into place by a derrick car. They were utilitarian in the strictest sense, regarded either as unattractive or as an epitome of functionalism, but mostly they were politely ignored.

Federal programs to eliminate dangerous road and track crossings at grade in the late 1920s led to an increase in the use of plate-girder bridges, particularly in urban areas. Possibly the first effort to "beautify" a plate girder was made by the Westchester County Parks Commission in 1929. Jay Downer, engineer for the commission, designed a deck plate-girder highway bridge with an arched

The Edison Bridge did not win any aesthetic awards, but its design was true to the doctrine of functionalism in which Morris Goodkind strongly believed. By the late 1930s, the era of adding extraneous decorative details to bridges was over. Clean lines, graceful curves, linear shadow lines, and the repetition of simple shapes such as floor beam extensions to support the sidewalks and the vertical stiffeners of plate girders, were viewed as aesthetically pleasing representatives of the "pure form" of engineering science. The bottom chord of the girders was left flat and deepened at the supports, distinguishing it from the more expensive curved type that was winning appearance awards. Source: NJDOT.

web and bottom flange (or chord) to span railroad tracks in Mt. Pleasant, New York. The bridge won the AISC award that year for most beautiful short-span bridge, apparently a first for the homely plate girder. New Jersey followed suit, winning the AISC award in 1933 for a multi-span plate-girder and bascule bridge over the Shark River, also with curved bottom chords. Although more expensive to fabricate, the curved bottom chord on deck plate girders decreased deflections on longer spans and provided a more pleasing appearance.

Bridge aesthetics played an important role in the New Jersey Highway Department under its chief bridge engineer Morris Goodkind. Goodkind and his design staff had an eye for good aesthetics and captured many AISC awards over the years, beginning in 1932 with the Pulaski Skyway bridges.

The discussion of bridge aesthetics came to fruition in the 1930s and was due in part to the AISC awards, which rekindled the old debates on what constituted good aesthetic bridge design and what role, if any, architects should play. In 1934 Harry Engle, a bridge engineer with the firm of Mojeski, Masters and Case in Philadelphia, dropped the first bomb with an article called "Art in Bridge Building," published in *Civil Engineering*. Engle believed in functionalism, that "bridges should be ornamented only to emphasize the design conceived by the engineer" and that "beauty is inherent in a properly and scientifically designed structure." Engle pointed to the towers of the Washington Bridge where the masonry facing was left off for economy and the growing opinion was that the bare steel possessed a "Machine Age beauty" that added to rather than detracted from their appearance. He concluded that designs of true beauty must originate with the engineer, leaving the architect only in the role of a collaborator to contribute to the attractiveness of the final design.

Arthur J. Lichtenberg, a bridge designer with the New Jersey State Highway Department, fired off the first letter of protest, stating "it does not necessarily follow that a structure designed by an engineer will possess the elements of beauty simply because it is functional." Lichtenberg concluded that the best interests of the public would be served if the engineer and architect collaborated from the inception of the design. This opinion was expressed in most letters and papers on the subject that followed over the years.

In February 1935, at the annual convention of the American Concrete Institute, Morris Goodkind presented a comprehensive paper entitled "Architectural

Considerations in Bridge Design." Goodkind had obviously put great thought into the subject, stressing the importance of aesthetics while offering many specific do's and don'ts: "of primary importance is that the bridge express truth . . . its parts should exhibit a clear explanation of its purpose. . . the masking of surfaces or the members without visible justification or the use of lines foreign to the structural design leave a false impression and should be avoided as lacking artistic worth. . . efforts to imitate materials such as stone by the use of scorings in concrete surfaces should be discouraged as being deceptive. . . essential to a beautiful structure is simplicity. . .meaningless ornamentation and embellishment merely detract attention from important features and serve to irritate rather than please the observer." Goodkind's paper covered all aspects of the subject in a systematic, no-nonsense fashion that, when the paper was published, left critics completely and mysteriously silent.

Numerous other important papers on bridge aesthetics were published in the 1930s, most notably those by engineering professors J.K. Finch of Columbia and Leslie Schureman of Princeton, by Wilbur J. Watson, a consulting engineer and author of the 1926 landmark book *Bridge Architecture*, and by Aymar Embury, an architect and engineer who collaborated as architectural consultant with D.B. Steinman and others on several major bridge projects.

No one had anything to say about plate girders, however, except the AISC, which continued to give them awards. A notable advance in the aesthetics and technology of the plate-girder highway bridge in the United States was demonstrated by the Capital Memorial Bridge in Frankfort, Kentucky, built in 1937. It was the longest continuous plate girder in the United States, and its gracefully curved bottom chords achieved nearly the maximum theoretical slenderness ratio, earning it the AISC award in its class for that year.

World War II stalled discussion of bridge aesthetics, but the post-war building boom of highway bridges brought it back to the forefront. In 1949, the Department of Architecture at the Museum of Modern Art in New York undertook a study of bridge architecture in an effort to raise the quality of American bridge design. The resulting book, *The Architecture of Bridges*, was written by the Department's curator, Elizabeth B. Mock, and published with a grant from the American Bridge Company, a subsidiary of U.S. Steel Corporation. Mock found the plate girder "immobile and a bit dry" and "likely to seem gross" in long heavy spans, "but a good simple elementary form, orderly and restful . . . pleasantly unobtrusive but notably elegant." Mock stresses that "because of its lack of structural drama the plate girder more than any other bridge depends upon justice of proportions and perfection of detail."

Over the second half of the 20th century, the continuous deck girder bridge became one of the most widely used bridge types in the world. German improvements in deck designs led to thinner and longer girders with gracefully arched bottom chords of undisputed beauty. The discourse on bridge aesthetics continues today as new bridge forms are developed and grand old bridges are replaced.

AESTHETIC AND TECHNOLOGICAL CONCEPTS FOR THE NEW ROUTE 9 SOUTHBOUND BRIDGE AND THE REHABILITATION OF THE EDISON BRIDGE

After 62 years of service without a major reconstruction, the Edison Bridge was in need of complete redecking and rehabilitation. In order to maintain traffic flow along Route 9 during rehabilitation and improvement of the existing substandard bridge geometry, the New Jersey Department of Transportation (NJDOT) decided to build a new bridge, parallel to the Edison Bridge.

In June 1999, NJDOT awarded a contract for the construction of a new southbound bridge. The new bridge was constructed in the space between the Edison and Driscoll bridges. It was configured to first carry both bounds of Route 9 traffic in order to permit closing of Edison Bridge for rehabilitation. Upon completion of rehabilitation, the Edison Bridge was converted to carry northbound traffic only. The newly constructed bridge carries Route 9 southbound traffic.

Edison and Driscoll bridges had created a certain visual order through the number and length of their spans, the locations of their piers, their profiles, and their superstructure types. Although not identical, their pier shapes are similar. The Edison Bridge had two-column piers while Driscoll Bridge had three-column piers. The detailing and shapes are also similar but not identical as the intricate details of concrete construction used in the 1930s were not used or replicated in the 1950s.

The contemporary design selected for the new southbound bridge applies 21st-century techniques and technologies, and yet it is visually compatible with both existing structures.

As a result, the pier locations and span length of the new bridge replicated that of the Edison Bridge. The new bridge, however, was designed to be lower than the Edison Bridge, providing a more gradual vertical profile in order to improve stopping sight distance and thus enhancing traffic safety on the bridge.

The piers were constructed as two-column piers without a mid-height strut as modern design techniques do not mandate its use. The columns were constructed more economically of uniform and smaller rectangular sections. Nevertheless, the bases of the piers were designed with steps to replicate the ornamental base of the Edison Bridge piers, and *haunches* were introduced at the top of the columns for functionality and to provide a visual transition from column to horizontal cap beam.

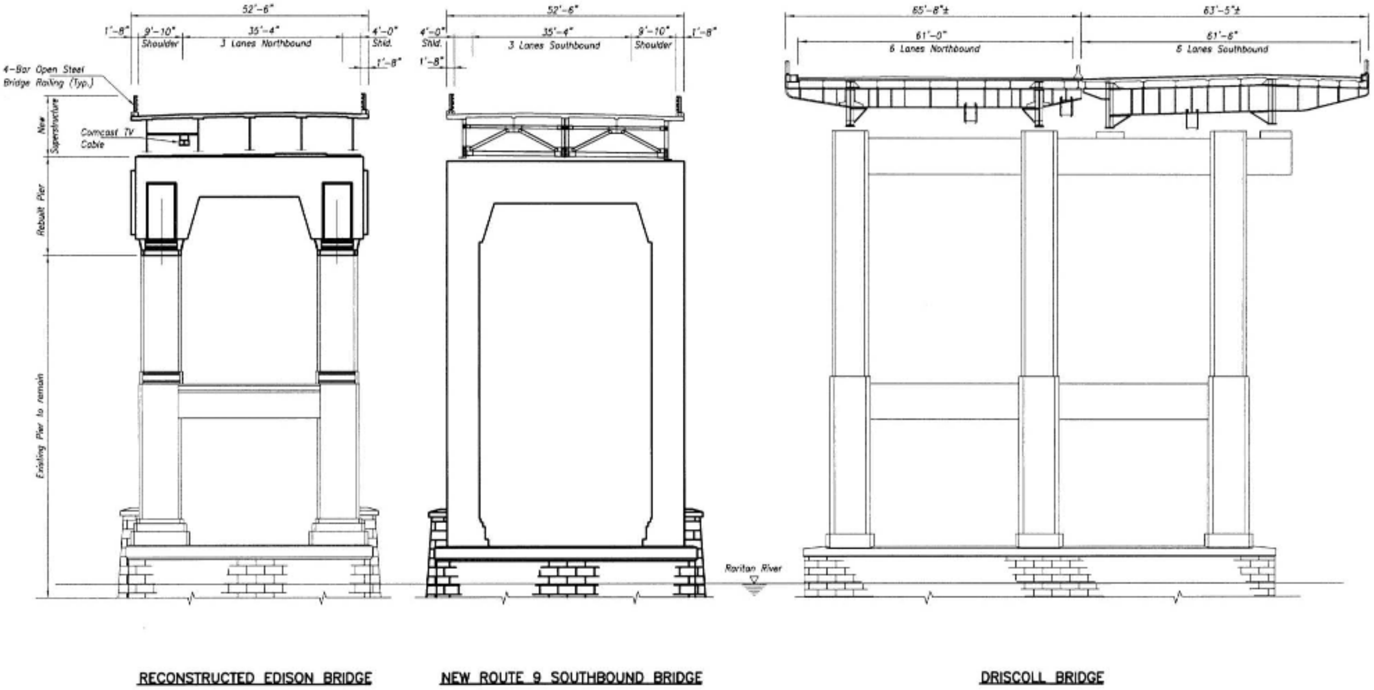
The river piers of the Edison Bridge and the Driscoll Bridge were protected by granite stone masonry against ice and other objects that might float by. The piers of the new bridge are protected with high performance concrete, a mixture that offers enhanced durability and strength. However, to visually complement the look of stone masonry, a recently developed technique that uses formliners to texture and shape concrete surfaces was used to create the appearance of granite masonry protection.

Modern design and construction techniques were also used in the superstructure and deck construction of the new bridge. Both existing bridges were constructed of two main steel plate girders and steel floor beams with brackets and steel stringers. The design for the new bridge, however, uses a structurally redundant framing system that provides back-up support for the roadway.

The new bridge spans over the river were designed with continuous steel plate girders of three main girders with two substringers supported by cross frames. The main girders were seated on top of the pier cap beam by means of multirotational bearings.

Girders were of prismatic design and approximately 8' in depth, except for a taper needed for transition to a girder depth of 10' in the span above the navigation channel. This system was found to be most economical for the number and length of river spans. However, for the somewhat shorter approach spans over land, a girder framing system using prestressed concrete was selected.

Essentially five lines of prismatic girders, approximately 6.5' deep were used in the bridge superstructure over the land north and south of the river. The girders were of precast prestressed construction and were made continuous by post-tensioning to form two units of continuous girders at the south and at the north approach spans respectively. At the north end, where the spans were longer (155' to 173'), a technique of spliced girders was used. The girders consisted of



GARDEN STATE PARKWAY AND ROUTE 9 BRIDGES
AFTER WIDENING OF ROUTE 9

Garden State Parkway and Route 9 Bridges after Widening of Route 9
Note lower profile (top), pier changes (middle), and framing (bottom).

pier units and center portion units erected by means of a temporary steel support (strong back). The units were spliced (connected) into a continuous monolithic unit—again by post-tensioning. The girders were also integrally embedded in the cast-in-place pier cap, thus forming monolithic connection between *substructure* and superstructure. To achieve this, the pier caps and girders were post-tensioned transversely also.

These construction techniques were possible because of the modern high-capacity tall cranes that were operating in the narrow space between the existing bridges and the high-strength materials that permitted the design of economical and relatively light bridge components.

Rehabilitation of the existing Edison Bridge presented a different engineering challenge. The aim was to replace the entire superstructure with one of modern design that could be safely supported by the existing substructures. The vertical profile was lowered to match that of the new southbound bridge and to improve stopping sight distance. To achieve this, some of the piers will be cut shorter to accommodate the new superstructure. The aesthetic and technological aspects of the rehabilitation design are discussed below.

The most memorable aspects of the Edison Bridge as originally built were the shapes, proportions, and fine details of the superstructure, piers, and abutments. When built, the bridge reflected the highest standards of bridge design and craftsmanship current in the years between 1890 and 1940 in this country.

The overall aesthetic goal for reconstruction of the Edison Bridge was to maintain the proportions and details of the original bridge where reasonable, and to incorporate proportions and details reflective of the original bridge into the new elements. The result demonstrates how traditional craftsmanship and attention to detail can be married with modern materials to create an example of the bridge builder's art as attractive and memorable as the original.

Superstructure

The bearing stiffeners and the shapes of the main channel span haunches presented the major opportunities to emulate the quality of the original superstructure. The superstructure was notable for the haunches formed by reverse curves at the longer spans and for the detailing of stiffeners and brackets throughout, which created an intricate geometric girder pattern. The main channel haunches of the new superstructure are created with reverse curves that are similar to the original haunches. Triple stiffeners are used at the bearings to recall the stiffeners of the original bridge and also create a pattern on the girders which reflects the grooved rectangle on the pier just below.

The rehabilitated Edison Bridge remains a steel plate-girder bridge, but modern welding and design techniques have reduced the need for stiffeners. The rebuilt bridge uses a five-girder system rather than the two-girder system of the original bridge. The five-girder system reduced the required depth of the girders, removed the need for brackets, and now provides the structural redundancy necessary to ensure back-up support for the bridge.

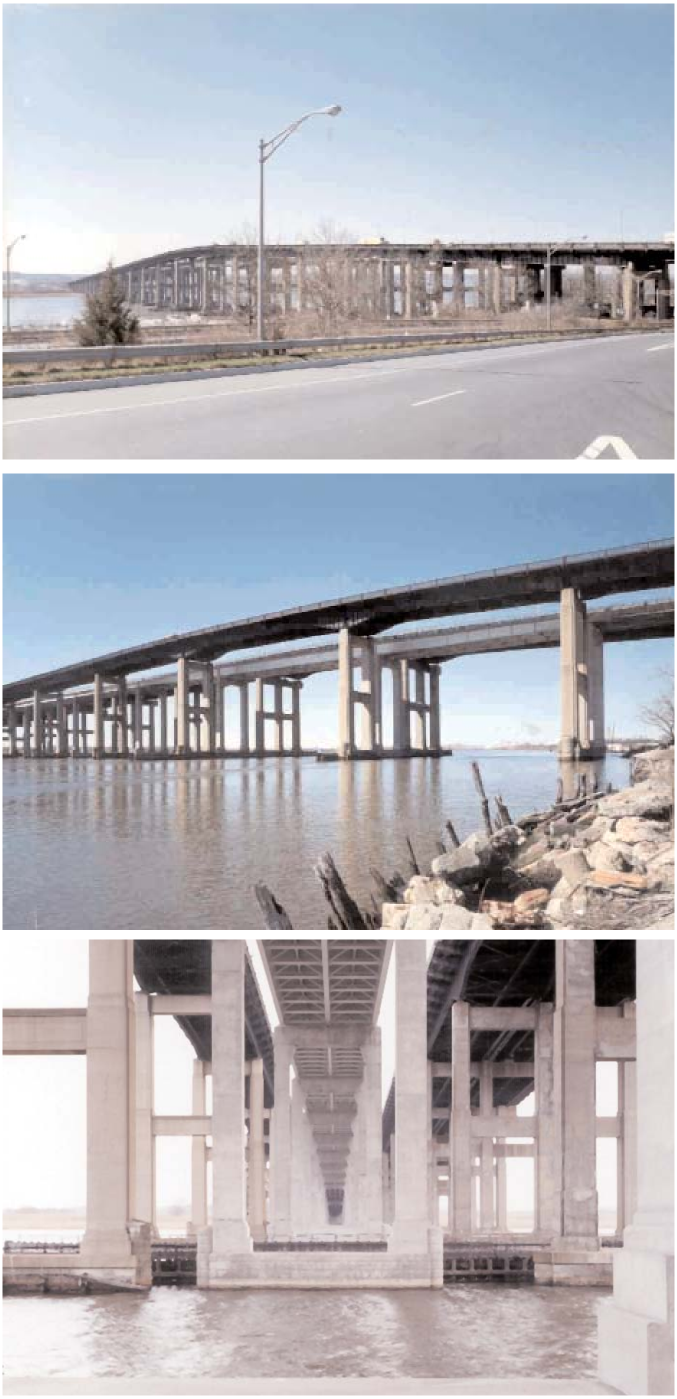
Piers

The piers of the Edison Bridge were notable for their fine proportions, which remained consistent from the tallest to the shortest pier, as well as for the corner indents, setbacks, and inset panels that were worked into the surfaces. The details remained impressive because of the excellent condition of the original concrete, which had aged to a beige color and had weathered to a uniform texture resembling coarse sandpaper.

An especially notable detail was the rectangle with three or five vertical grooves that occurred at the apex of each pier. The rectangle was sized proportionally at each pier according to the overall dimensions of the pier. This repeated feature drew the eye along the profile from pier to pier, visually highlighting the points of weight transfer from girder to pier.

Because of the combined effects of the shallower superstructure and the need for a lowered profile grade over the channel, all of the Edison Bridge piers were rebuilt at a different height. Some had to be raised as much as 10', and some had to be lowered.

The concept for the rebuilt piers incorporated a new standard of pier top in the shape of an inverted U and consisted of the new pier cap and short sections of the columns with a haunch (tapered section) on the inside face of the columns. The haunch reflects the new structural function of the pier cap and establishes an obvious visual break at the point where the original columns were cut. The



Garden State Parkway and Route 9 Bridges after Widening of Route 9. Note imitation of granite masonry at pier base (bottom).

depth of the pier cap and length of the column haunch were established by reference to the depth of the horizontal strut of the original pier. This assured that the proportions of the rebuilt pier were consistent with the proportions of the original pier.

Decorative elements of the existing piers, particularly the grooved rectangle, were replicated and incorporated into the rebuilt piers. These decorative elements are constructed of precast concrete that is colored and textured to match the color and texture of the existing piers. The rest of the new pier cap and haunch sections have the natural color of new concrete.

The dimensions of the decorative elements were adjusted at each pier to fit the pier's proportions. The color and texture of the decorative elements connects them with the historic portions of the bridge and differentiates them from the new structural elements.

The outer girders of the new five-girder system are set slightly outside of the original girder locations. Small *cantilevers* were required at each pier to support these girders. Decorative elements based on original decorative elements helped to integrate the small cantilever required by the new outer girders into the overall form of the piers.

Abutments

The most notable features of the abutments were the Art Deco end-block pilasters with patterns of glazed tile on the exterior surfaces. Because the roadway of the rebuilt superstucture is slightly narrower, it was not necessary to make any changes to these pilasters.

The only change to the abutments that was necessary was to add narrow pilasters along the abutment faces to support each of the five girders. These are the color of new concrete, again differentiating new structural elements from the historic bridge. However, since the new pilasters were placed within the existing end-block pilasters, as seen against the face wall, they are relatively inconspicuous.

Railings and Light Poles

The new Route 9 Southbound Bridge and the rehabilitated Edison Bridge are seen together by travelers on both bridges. Visual compatibility of the bridges was enhanced by coordinating the placement and color of the railings and light poles between the two bridges.

The four-rail galvanized and painted railing on the Edison Bridge matches the railing on the new Route 9 Southbound Bridge. The railings on both bridges are blue, which blends well with the blue and gold frieze on the abutment end block of the Edison Bridge.

The same gray light poles and fixtures are used on both bridges. The light poles on both bridges are laid out with the spacing symmetrical about the centerline of the main channel span. This places the poles into a consistent relationship with the major piers.

Colors

The colors of the Driscoll Bridge and the Route 9 Southbound Bridge are shades of gray, which would have been compatible with almost any color chosen for the Edison Bridge. As the Edison Bridge conceals the other two bridges from view when looked at from the east, and the other two bridges hide the Edison Bridge in views from the west, the color of the Edison Bridge did not need to be restricted by the color of the other bridges.

Since the superstructure of the Edison Bridge is new, there was no compelling reason to use black, which is the historic color of the bridge. However, the colors in the original glazed tile work—blue, gold, and light red—suggested the choice of blue for the deck elements.

Aesthetic Advantages

The new superstructure of the Edison Bridge is different in depth and shape from that of the new Route 9 Southbound Bridge. While both land and river spans of the Edison Bridge are steel, the land spans for the Route 9 Southbound Bridge are concrete, and its river spans are steel. Although there are differences between the bridges, the following aesthetic advantages have been realized:

- In general, built elements should reflect the technology and materials of the time when they are built. High-strength concrete and steel, and new methods of computerized analysis are now available and lead to forms quite different from the forms of sixty years ago. As an entirely new bridge, the Route 9 Southbound Bridge reflects these forms.

  The rehabilitated Edison Bridge also reflects the times in which it was built. The past achievements of technology are preserved in its substructure design, and advances that have been made since the bridge was built are evident in its new superstructure.

- Because the Route 9 Southbound Bridge is not visible from important downstream viewpoints, views of the complementary designs of the Edison Bridge and the Driscoll Bridge are preserved.

- When viewed from the east, the Edison Bridge will stand out among the trio of bridges. Height differences among the bridges will allow the viewer to appreciate the slender superstructure and well-proportioned piers of the Edison Bridge.

- The combination of the Edison Bridge, the Driscoll Bridge, and the new Route 9 Southbound Bridge tells the story of bridge construction over the last sixty years. The rehabilitated Edison Bridge recalls a bridge of the 1930s, the Driscoll Bridge is illustrative of a bridge of the 1950s, and the new Route 9 Southbound Bridge represents a bridge of the 21st century.

BRIDGE TERMINOLOGY & GLOSSARY

Abutment: a structure, usually stone or concrete, that supports one end of a bridge span and the embankment carrying the roadway or track.

AASHTO: American Association of State Highway and Transportation Officials. A professional organization advancing highway design and construction by establishing engineering standards and specifications (formerly AASHO).

Bearing: (also shoe) a device that transfers loads from superstructure to substructure; can be fixed, expansion, or sliding with many subtypes of each; usually allows movement, especially horizontally due to thermal expansion. Some bridge types designed without bearings.

Cantilever: projecting beam or structure anchored at one end to a pier and projecting over space to be bridged; allows bridge erection without falsework; trusses, plate girders and box girders can be built as cantilever bridges.

Car Float Barge: a very large barge equipped with tracks designed to ferry railroad cars across un-bridged waterways such as New York Harbor.

Continuous girder: a girder supported at three or more points; bending forces in the center of the span are reduced by opposite forces acting at the piers.

Dead load: weight of all the parts of the bridge and any imposed fixed loads on the bridge such as tracks, lighting, utility lines; see live load

Deck: floor or roadway of a bridge, often reinforced concrete; structural function is to distribute loads transversely; carried by or integrated with primary structural members such as stringers and girders.

Deck bridge: bridge with deck above superstructure.

Falsework: temporary wood or steel structure erected like scaffolding to support construction of a bridge; called centering when used for arches.

Field splicing: the joining of sections of a girder or other structural member of a bridge with rivets, bolts or welding at the bridge site.

Flange: the top or bottom member of a beam or girder that resists tension or compression.

Haunch: an increase in the depth of a member, usually at points of support.

Live load: a temporary or moving load imposed on a bridge or structure by persons, vehicles, wind.

Moment: the tendency to cause rotation around a point or axis; i.e., a bending moment tends to produce bending in a beam.

Moment distribution method: structural analysis method for indeterminate structures like continuous beams using a series of approximate solutions repeatedly to obtain increasingly smaller corrections.

Photoelastic analysis: a method of observing stress patterns in certain transparent materials using polarized light; used to analyze plastic models of bridges and predict behavior under various loads.

Plate girder: a type of beam; see figure on page 16.

Prestressed concrete: concrete strengthened by the application of tensile force to the reinforcing tendons, either before the concrete has hardened (pre-tensioned) or after (post-tensioned).

Reversal stresses: stresses in members that change from tension to compression or vice versa; early continuous structures were shunned by some who considered them susceptible to dangerous stress reversals resulting from differential settlement of the substructure.

Rigid-frame bridge: usually concrete, deck and abutments are rigidly joined; abutments function as legs to resist deck loads through torsional strains transmitted by the rigid connection; overturning forces on abutments are resisted by deck.

Screed: a device used for spreading and striking-off fresh concrete to achieve a uniform surface of desired slope and grade.

Simple beam: a beam with its ends free and resting on only two supports.

Simple span bridge: a bridge consisting of beams or elements that begin at one support and end at an adjacent support

Statically indeterminate: structures that cannot be structurally analyzed by the principles of statics.

Substructure: the piers and abutments and their foundations, which support the superstructure and transmit the loads to the soil or rock.

Superstructure: the portion of a bridge above the piers and abutments; purpose is to carry the deck across the obstruction being bridged.

Through or thru bridge: bridge with the deck passing through the superstructure.

Truss: a jointed structure made up of individual members arranged and connected, usually in a triangular pattern, so as to support longer spans

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Morris Goodkind
Chief Bridge Engineer - New Jersey Highway Department
1925-1955

Morris Goodkind (facing camera) inspecting construction of Edison Bridge, 1939.

Morris Goodkind was born in New York City in 1888 and graduated from Columbia University in 1910 with a degree in civil Engineering. Following school, he worked with the city of New York preparing plans for the subway system. He joined the engineering firm of Albert Lucius in 1912 as an assistant engineer. Lucius had engineered elevated railway systems for New York and Brooklyn in the late 1800s, and was specializing in the design of railroad bridges when Goodkind joined him. Goodkind worked in Lucius's office between 1912 and 1914, and undoubtedly it was here that his interest and skills in bridge design were first honed.

During his early career years, Goodkind moved between jobs in the public and private sector. He worked for New York's Interboro Rapid Transit Corporation and the J.G. White Engineering Corporation. From 1919 to 1922, he worked as county bridge engineer for Mercer County, New Jersey.

In 1922, Goodkind joined the New Jersey Highway Department as general supervisor of bridges. He was named Chief Bridge Engineer in 1925, a position he held until his retirement in 1955. He received numerous awards and honors for his work over the course of his career with the state. His most prestigious bridge award was the Phoebe Hobson Fowler Medal, given by the American Society of Civil engineers for his design of the College Bridge, a multi-span concrete arch carrying U.S. Route 1 over the Raritan River. The bridge has since been renamed the Morris Goodkind Memorial Bridge.

Goodkind also won several "most beautiful bridge of the year" awards, given annually by the American Institute of Steel Construction. Among the winners were Oceanic Bridge over the Navesink River (1940); Passaic River Bridge between Newark and Kearney (1941); and Absecon Boulevard Bridge in Atlantic City (1946). During World War II, Goodkind consulted for the War Department, aiding the Army Corps of Engineers in bridge design and construction. He was awarded the Tau Beta Pi Achievement Certificate from Rutgers in 1948 and an honorary Doctor of Engineering degree from Newark College of Engineering in 1950. He served as Consulting Bridge Engineer for the building of the Garden State Parkway in the early 1950s. After retirement from the Highway Department in 1955, he was a partner in the firm of Goodkind and O'Dea, which currently operates under the name of Dewberry-Goodkind, Inc. In 1958, Goodkind was granted the Egelston Medal by Columbia University, their highest award for engineering achievements. Morris Goodkind died September 5, 1968.

New Jersey Department of Transportation
Trenton, New Jersey

THE Louis Berger Group, INC.
East Orange, New Jersey