

Modena viaducts for Milan–Naples high-speed railway in Italy

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In 1991, the design and construction of infrastructure and plants for the Italian high-speed railway between Milan and Naples was commissioned. It included the design and construction of the 113 mi (182 km) section between Milan and Bologna. The €4.89 billion lump-sum contract included a warranty for schedule, cost, and quality from the contractor.

The work was divided into 19 lots (13 lots of civil works, 3 lots of railway plants, and 3 lots of technological plants), and the design and construction of the 19 lots were distributed to the firms participating in the consortium. This paper is based on the tasks of one of the subconsortia, which was assigned the 24.5 mi (39.5 km) civil work lot from kilometer 142 + 685 to kilometer 182 + 148, the 4.9 mi (8.0 km) duplication of the Modena–Mantua line, and the new stations of Modena and Soliera.

The tasks included the 15.4 mi (24.8 km) Modena viaducts, the 5.7 mi (9.2 km) bridges of the Modena east and Lavino interconnections, an additional 1.1 mi (1.8 km) of bridges crossing four rivers and six railroads, 0.3 mi (0.4 km) of cut-and-cover tunnels, and tens of box culverts. Tasks also included 15.5 mi (25.0 km) of railway embankment inclusive of base geo-synthetic protection, anticapillarity layer, super-compacted upper layer, and subballast layer in asphalt concrete.

The construction of the Modena viaducts had a schedule of 30 months.

- Construction of the 15.4 mi (24.8 km) Modena viaducts for the Milan–Naples high-speed railway in Italy required precasting 755 spans and in-place casting 9 three-span continuous bridges in 30 months.
- This paper describes the quality control processes used to meet the requirements for schedule, budget, and quality.

Modena viaducts

The railway alignment is far from the infrastructural corridor of Highway A1 Milan–Naples in the agricultural eastern area of Modena. Mitigating the visual and acoustic effects of the new infrastructure was therefore a primary concern. The number of local roads, farm roads, rivers, and irrigation channels to be crossed and the poor mechanical properties of the soil prompted the use of long bridges instead of embankments. Bridges also facilitate water flow during floods of the River Po and avoid the hydraulic problems of so many underpasses.

The Modena viaducts include five main structures. The 1.3 mi (2.1 km) Brenner viaducts are two adjacent bridges overpassing Highway A22. The 4.4 mi (7.1 km) Modena viaducts are two adjacent bridges overpassing the new railway lines of Modena west interconnection and the River Secchia. The 1.5 mi (2.4 km) Secchia viaduct is a one-way bridge over the River Secchia, the Modena north industrial area, and the Modena west interconnection. The 0.9 mi (1.5 km) Panaro viaducts are two adjacent bridges over the River Panaro, and the two bridges of the Modena west interconnection span rivers and local roads and have a total length of 0.6 mi (1.0 km).

Bridges that would have been so long and so low to the ground were an unusual challenge in terms of visual and acoustic effect. They were nicknamed omega viaducts from the particular shape of cross section that was adopted. The 11.5 ft (3.5 m) high omega section envelops the lower noisy portion of the train and acts as a noise barrier. A conventional box girder with noise barriers and deck-slab ballast would be about 24.6 ft (7.5 m) high, so the omega section also dramatically improved the visual appearance of the bridge.

Further improvements were achieved with an elliptical profile engraved with wide waves to reflect the sunlight at different angles, and a rounded shape for the span bearing blocks mirrored into the pier caps. The pier shafts are devoid of rustications for a feeling of elegance and simplicity.

The Modena viaducts comprise 755 simply supported precast concrete spans and 9 three-span continuous bridges. Of the precast concrete spans, 713 units are 103 ft (31.5 m) long, 28 units are 95 ft (29.0 m) long, and 14 units are 79 ft (24.0 m) long. The continuous spans are 446 ft (136.0 m) long and have spans of 131 ft (40.0 m), 184 ft (56.0 m), and 131 ft (40.0 m).

The footings of the precast concrete spans are supported by 4.9 ft diameter (1.5 m) drilled shafts with lengths ranging from 115 ft (35.0 m) to 164 ft (50.0 m). The footings of the continuous spans are supported by perimeter caissons of 3.9 ft thick (1.2 m) slurry walls.

The piers are solid with a diameter of 11.5 ft (3.5 m) for the precast concrete spans, and hollow with a diameter of 15 ft (4.5 m) for the continuous spans. The pier caps comprise the span support and retaining systems, the antiseismic devices, and the dewatering systems, and they allow easy inspection.

Span precasting plant

The precast concrete spans were all to be moved along the constructed bridges, so the first task was identifying the most appropriate location for the precast concrete plant in relation to the project schedule for the three-span continuous bridges. A 35,900 yd² (30,000 m²) area was identified adjacent to the Modena viaducts, and a brand-new, high-tech precast concrete plant was designed starting from scratch.

The plant included storage areas for reinforcing bar and bulk materials, a 13,200 yd² (11,000 m²) shed for fabrication of reinforcement cages, a 7200 yd² (6000 m²) shed for casting of the spans, a front storage area for 16 precast concrete spans, a 2700 yd² (2300 m²) shed for fabrication of twin box girders for the remaining bridges of the lot, a three-line batching plant with two-line mixing tower, 4200 yd² (3500 m²) of storage for six classes of sand and aggregates, and a logistics area. **Figure 1** shows an aerial view of the plant.

Span prefabrication process

Fabrication started with the reinforcement cages in a 484 × 144 ft (147.5 × 74.4 m) shed. Eight cage templates, each as long as an entire span, were assisted by four 28.1 kip (125 kN) gantry cranes. Cage prefabrication included placement and geometry adjustment of the end bulkheads, fixing of the anchorages of prestressing tendons, assembly of reinforcement, fabrication and sealing of 20 plastic prestressing ducts, insertion of twelve 0.6 in. (15 mm) strands into each duct, and application of all embedded items. After the learning curve, fabrication of the 74 kip (330 kN) cage for the standard span took on average four days for 11 ironworkers, so two cages were completed daily.

Initially the span carriers were also used to move the cages from the templates to the casting cells (**Fig. 2**); eventually the increasing delivery time of the spans required the use of a specific wheeled carrier.

A 438 × 122 ft (133.5 × 37.2 m) shed lodged the forming systems for the omega sections. Two parallel casting lines comprised three fixed exterior forms and a wheel-mounted interior form running onto rails (**Fig. 3**); each casting line was assisted by a 28.1 kip (125 kN) gantry crane. The exterior forms had independent water and compressed-air plants, and the interior form was equipped with two hydraulic distribution arms for concrete feeding. After



Figure 1. Precasting facility.



Figure 2. Cage delivery to the form.



Figure 3. Movable interior form with concrete distribution arms.

placing the prefabricated cage into the exterior form, the interior form was moved into the cage to close the casting volume.

Concrete was pumped from the mixing tower of the batch plant (**Fig. 4**) to the distribution arms of the interior form through two independent wear-resistant pipelines reaching the six casting cells through a network of underground passages. Each feeding line included a 4.2 yd³ (3.2 m³) horizontal turbo-mixer, a 9.2 yd³ (7.0 m³) hydraulic agitator, a concrete pump, hydraulic deviators at the nodes of the pipeline network, and the 52 yd³/hr (40 m³/hr) tower-mounted distribution arm. Upon completion of span casting, the hydraulic deviators fed two washing tanks with the residual concrete and the pipeline washing water. Electrical agitators prevented setting, aggregates and sand were recovered, and the residual water fed the washing points of truck mixers or was recycled in batching new concrete.

The batch process was fully automated and the batch rate was controlled by level probes in the agitators and concrete pumps. The batch plant was also equipped with a truck-mixer feeding point for the other structures of the project

and as an emergency line in case of failure of the mixing tower.

Seventy-six wall-mounted varying-frequency electric vibrators on the exterior form and 28 vibrators on the interior form vibrated concrete and removed air bubbles. A standard 103 ft (31.5 m) span required 361 yd³ (276 m³) of 6500 psi (45 MPa) concrete, which was fed in 4 hours. The precasting plant was designed to cast two complete spans a day.

After 12 to 18 hours of ambient-temperature curing, the interior form was stripped and moved to the next casting location, and the end bulkheads were moved back to the cage prefabrication templates. Tensioning the prestressing tendons to 38% of the final stress allowed the 1600 kip (7000 kN) span to be lifted from the exterior form (**Fig. 5**) and transferred to the storage area.

The permanent bearings were placed on the support blocks of the storage area before lowering the span onto them. Two- to five-day storage was necessary to complete posttensioning, grout the tendon ducts, seal the tendon



Figure 4. Batch plant.

anchorage, grout the bearing bolts, inspect and finish the surfaces, and perform the numerous pretransportation checks of the quality control process (**Fig. 6**).

Span placement process

Two custom-fabricated portal carriers were used to move the precast concrete spans from the form to the storage area and then to the final location. The span carriers, each 34.4 ft (10.5 m) tall and 190.0 ft (57.9 m) long, comprised two wheeled trolleys connected by a box girder supporting two lifting winches (**Fig. 7**). Movement and steering of the trolleys were governed by hydraulic motors, and the hydraulic plants were powered by diesel engines.

The distance between the centerlines of the rear (master) trolley and the front (slave) trolley was 148 ft (45.0 m). Longitudinal cylinders shifted the rear hoist winch to the suspension points of the different types of precast concrete spans while the front winch was fixed.

Picking up the precast concrete spans from the form and the storage area involved a complex sequence of operations. The carrier was moved alongside the span, and the

trolleys were rotated 90 degrees by pivoting around a central hydraulic support strut. Then the carrier was moved transversely over the span (**Fig. 5** and **7**). After lifting the span, the carrier was moved back to the initial lateral location and an opposite 90-degree rotation of the trolleys realigned the unit to the transportation configuration.

After reaching the inlet of the viaduct, an automatic drive system controlled by ultrasonic sensors governed the movement of the carriers within the omega section (**Fig. 8**). The automatic-drive speed was 1.9 mph (3.0 km/h) at full load (more than 2250 kip [10.0 MN]) and 3.7 mph (6.0 km/h) when unloaded.

At the front end of the bridge, the front slave trolley reached the rear end of the 256 ft (78 m) underbridge. A self-propelled support saddle running onto the underbridge was moved backward underneath the front trolley to lift it and release its wheels. Then the front support saddle and the rear master trolley moved the carrier forward (**Fig. 9**) until reaching the span lowering location. The master trolley was locked and the underbridge was launched forward to clear the lowering area (**Fig. 10**).



Figure 5. Span being lifted from the form.



Figure 6. Span storage.



Figure 7. Span being lifted from the storage area.



Figure 8. Span being transported.

The lower counter-plates of bearings were embedded into the pier-cap seats prior to span transport. The counter-plates of the rear fixed bearing, the rear transversely movable bearing, and the front longitudinally movable bearing were set at the final elevation, while the counter-plate of the front multidirectional bearing (devoid of embedded bolts) was set 0.2 in. (5 mm) below the design elevation. The span was lowered onto four load cells placed onto the lower counter-plates of bearings; after adjusting the support reactions to the design tolerance with stainless-steel shims

at the movable bearing, the span was lifted to remove the load cells and finally lowered onto the pier (**Fig. 11**). After releasing the span, the underbridge was moved backward to release the front trolley onto the newly added span for a new placement cycle.

Continuous spans

The precast concrete spans were too short to cross Highway A22, the rivers Secchia and Panaro, and the Modena



Figure 9. Front trolley advancing along the underbridge.

west interconnection. Therefore, nine 446 ft (136 m) three-span continuous bridges were cast in place. These bridges also adopted the omega section for aesthetic continuity, though the negative moment from spans of 131 ft (40.0 m), 184 ft (56.0 m), and 131 ft (40.0 m) required the use of higher webs at the piers.

Two movable scaffolding systems and a pile-based falsework were used to cast the 1710 yd³ (1310 m³) continuous spans in three 174 ft (53.1 m), 188 ft (57.4 m), and 84 ft (25.5 m) segments. Every superstructure contained 36.0 kip (160 kN) of mild reinforcement and 24.8 kip (110 kN) of prestressing bars.



Figure 10. Forward launching of the underbridge.



Figure 11. Final lowering of the span.



Figure 12. Main movable scaffolding system.

The main 2900 kip (13,000 kN) movable scaffolding system comprised two overhead trusses suspending the exterior form (**Fig. 12**); the casting time of a three-span superstructure was about four months. The trusses of the main movable scaffolding system were 360 ft (110 m) long and carried a three-hinge portal crane for handling of reinforcement and insertion of the interior forms. The central section of each truss comprised two paired trusses holding the anchorages of the form hangers; the interior truss was interrupted at the end of the form suspension area while the exterior truss was extended into two launching noses. A third lighter truss controlled out-of-plane buckling and supported the runway of the portal crane; the auxiliary truss

was also extended to the launching noses. **Figure 13** shows the work area during assembly of reinforcement.

Upon completion of the exterior form assembly, vertical cambers were set by jacking the form hangers at the truss anchorages. Camber analysis was particularly accurate to meet the tight geometry tolerances of the quality control specifications. The structure-equipment interaction was analyzed during segment casting, at the application of prestress, and during lowering of the movable scaffolding system. The deflections of trusses and forms were measured under full load before the first use.

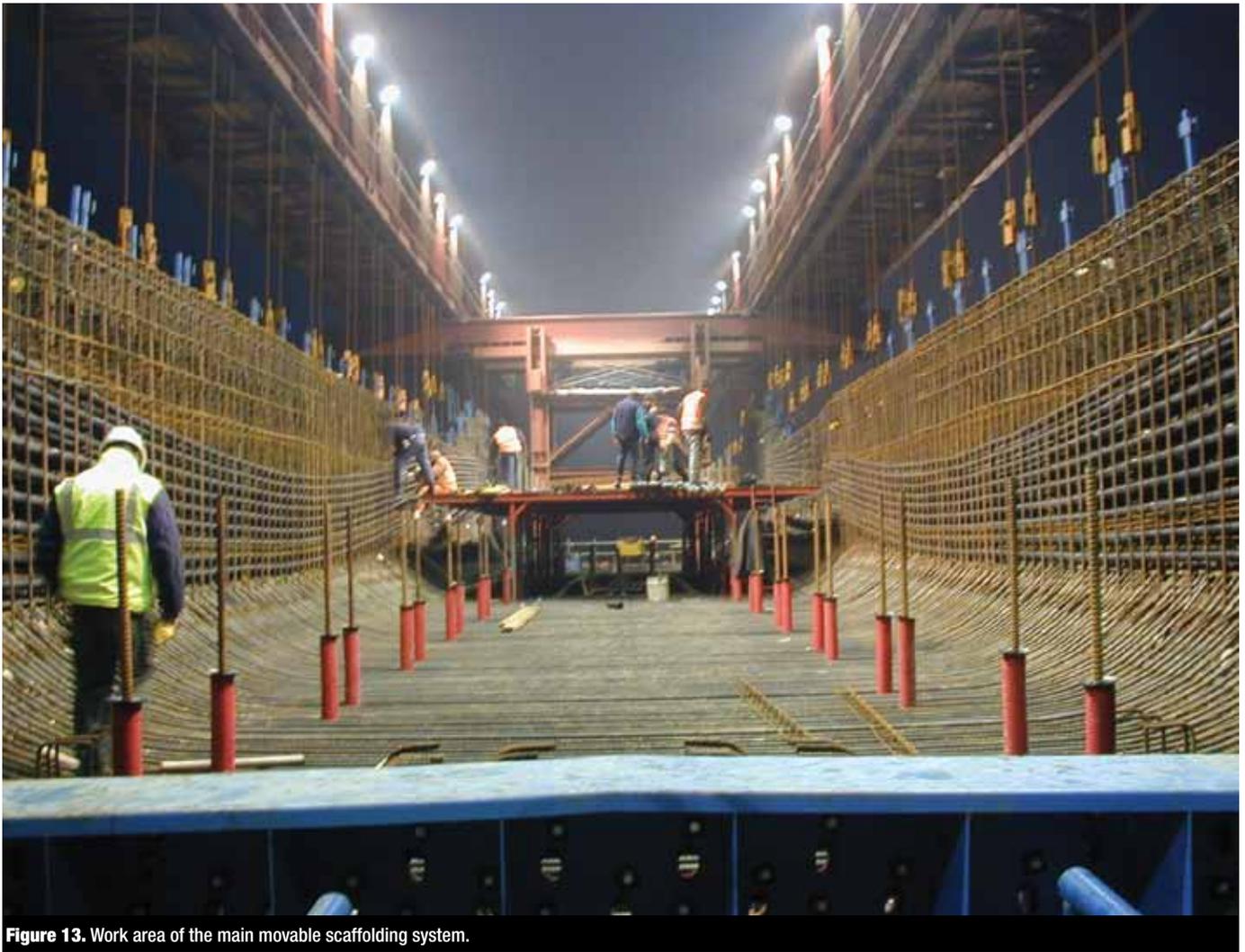


Figure 13. Work area of the main movable scaffolding system.

The first and second segments were cast using three concrete pumps, one for the bottom slab from midspan toward the rear pier, the second from midspan toward the front pier, and the third for the front cantilever. This sequence was designed to load the more deformable sections of the casting cell before the concrete set, which was retarded to 5 to 7 hours. The difference in the fluid concrete elevation in the two webs was kept less than 20 in. (500 mm) to control transverse load imbalance on the interior form. After casting the three segments, the movable scaffolding system was moved back to the casting location for the second segment and shifted transversely to the support towers of the adjacent bridge.

A simpler movable scaffolding system was used for the two continuous spans of the Secchia viaduct, and a pile-supported falsework was used for the two continuous spans of the Modena west interconnection bridges. Segmental construction of the continuous spans required application of temporary stresses to control the time-dependent stress redistribution in the bridges. A crossbeam anchored to the front end of the cantilever and pulling prestressing bars anchored to the footing increased the negative moment in the front support section to the value of monolithic cast-

ing. The pull in the bars was monitored in real time with electronic load cells.

Quality control qualification process

The quality control qualification process for plants and processes was complex. The batching plant, the precasting plant for the omega spans, the span carriers, and the two movable scaffolding systems for in-place casting of the continuous spans were all custom designs. The interaction of so many innovations was also reason for concern.

Quality control qualification was based on three milestones: written specifications for every operation, performance requirements and technical specifications for every primary component of equipment, and testing of operations and equipment before the first use.

The written specifications for operations defined sequences of actions, interferences with parallel operations, possible unforeseen events and remedial actions, geometrical tolerances, checks to perform, and people to refer to in response to nonconformities.



Figure 14. Completed bridge.

The performance requirements and technical specifications for the special bridge construction equipment defined operational requirements, design standards, analysis methods and level of detail, and checks to perform on materials and during fabrication and site assembly. Major construction equipment was subjected to independent design verification and load testing after site assembly.

Testing of operations involved prequalification of all materials and processes and casting full-scale sections of the omega spans.

Conclusion

Precasting 755 spans and casting 9 three-span continuous bridges in place allowed construction of 15.4 mi (24.8 km) of prestressed concrete bridges in 30 months under warranty for schedule, cost, and quality. The visual and acoustic effects of such long high-speed railway bridges were mitigated by an omega section with an elliptical shape engraved by wide waves to reflect the sunlight at different angles. The rounded span bearing blocks were mirrored into the pier caps for a feeling of elegance and simplicity. **Figure 14** shows a view of the completed bridges.

Acknowledgments

The bridges of the Modena System were designed by Macchi, professor at the University of Pavia, and Dante Sangalli. The main precasting facility was designed by Sercam. The span carriers were designed and manufactured by Deal and operated by SPIC, the self-launching under-bridges were manufactured by Comtec, the main movable scaffolding system was provided by Thyssenkrupp, and the secondary movable scaffolding system and the ground falsework were provided by Alpi.

The author, as technology consultant to the prime contractor, wrote the quality assurance/quality control specifications for bridge construction and the performance requirements, technical specifications, and design criteria for all bridge construction machines. As the independent design checker of these machines, the author wishes to thank Sangalli and the technical offices of Alpi, Comtec, Deal, Sercam, SPIC, and Thyssenkrupp for the great work done under tight schedules.

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About the author



Marco Rosignoli, PE, has served for 15 years as construction manager, project manager, bridge department lead, and technical director for prime European bridge contractors. For nine additional years, he has assisted

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Abstract

Construction of the 15.4 mi (24.8 km) Modena viaducts for the Milan–Naples high-speed railway in Italy required precasting 755 spans and in-place casting 9 three-span continuous bridges in 30 months under warranty for schedule, cost, and quality. In this paper, the contractor's bridge technology consultant describes how such a record-breaking accomplish-

ment was achieved. Qualifying the quality control processes for bridge construction took almost one year. Means-and-methods analyses and risk assessments were performed for every major activity, and contingency plans were identified and also prequalified. Performance requirements were identified for special bridge construction equipment; equipment design was subjected to full independent checking; and its fabrication, assembly, and use were ruled by specific quality control processes.

Keywords

Full-span method, mechanized bridge construction, movable scaffolding system.

Review policy

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