Construction of the Mgeni Viaduct on Main Road P577

OVERVIEW

The Mgeni Viaduct is a 410 m long incrementally launched bridge which forms part of the new main road P577 between KwaMashu and New Germany in KwaZulu-Natal. This fourteen km long route will provide the fifth main crossing of the Mgeni River in the Durban region and is located about 10 km inland from the coast line. Completion of the P577 will provide a direct link between the residential areas of KwaMashu, Ntuzuma and Inanda, and the New Germany / Pinetown conurbation further to the west. Planning and design of this road was completed by the mid 1990s, but construction was delayed until 2002 due to a lack of funds. The decision to proceed was based on the significant contribution that the road would make to the socio-economic development of the local communities, linking them to new employment opportunities and dramatically reducing the cost of transport. The Client was the KwaZulu-Natal Department of Transport.

The site of the Mgeni Viaduct is dominated by the steep rocky escarpment on the east bank of the river, which falls sharply to river level and rises gently towards the west. P577 is on a sag vertical curve at the position of the bridge and descends at a gradient of 9% through a deep rock cutting behind the left abutment before rising at a gradient of 7% behind the spill-through right abutment, which partially retains a 15 m high embankment.

The viaduct comprises twin prestressed concrete box girder decks with a total of nine spans made up of one of 34 m, one of 36 m, six of 50 m and one of 40 m in the direction of launching from east to west, and is supported by eight 6 m by 3,5 m featured hollow piers varying in height from 45 m to 18 m, which were founded on intact sandstone at shallow depth and constructed by sliding. The four tallest piers required stays during launching to prevent excessive horizontal deflections. Each deck is 3,7 m deep by 15 m wide to accommodate three 3,5 m traffic lanes, shoulders and 1,5 m sidewalks at the outer edge. The twin decks are separated by a 0,5 m gap, which is closed by heavy precast concrete T-sections to form a raised median between the carriageways.

Construction of the Mgeni Viaduct involved the downhill launch of the 10 000 tonne decks on the steepest downhill gradient involving this form

CONSTRUCTION OF THE MGENI VIADUCT ON MAIN ROAD P577

Technical Excellence category

KEY PLAYERS

Client KwaZulu-Natal Department of Transport
Professional Team HBL Joint Venture
Henwood & Nxumalo, SSI Engineers & Environmental Consultants, Linda Masinga & Associates
Main Contractor Rumdel Mgeni Joint Venture
Major Subcontractors and Suppliers Competition Construction cc, Salli Construction cc

1 Mgeni Viaduct with Main Road P577 in the background
2 Mgeni Viaduct construction in progress

of construction in South Africa to date and ostensibly not matched elsewhere. It was necessary to design the launch abutment for a maximum horizontal force of 10 500 kN to prevent the uncontrolled downhill slide of the deck, or in the event of the need to retract the deck uphill.

In order to counter the risk and difficulties associated with forces of this magnitude, the abutment was anchored back into the intact rock substrata, and the deck was strengthened to suit the contractor's temporary works system. This comprised sophisticated launch equipment imported from Spain, capable of launching or retracting the deck by the use of tie bars in conjunction with steel pulling sticks inserted through holes at regular intervals along the decks.

The successful completion of this structure without major incident testifies to the quality of the contractor's temporary works and control measures during the construction of this technically challenging project. The project is non-critical within the overall completion of MR577.

QUALITY OF DESIGN

The team involved in the planning, design and construction management of the Mgeni Viaduct had been together since 1981 when the first incrementally launched viaduct in South Africa was constructed across the Umhlatuzana River adjacent to the Mariannhill Toll Plaza on the N3 near Pinetown. The depth of experience of this team ensured that a high-quality design could be presented to the contractors.

FACTORS WHICH INFLUENCED THE DESIGN CONCEPT

The main physical determinants which influenced the configuration of the Mgeni Viaduct were the steep topography and the geological formations traversed by Main Road P577 and over which the structure was required to span. Selection of the height of the viaduct above the river and adjacent flood plain arose from the optimisation of the road vertical and horizontal alignments in terms of geometric standards and the combined cost of the road and bridge works.

At the outset several structural forms were considered, which included incrementally launched decks, various balanced cantilever configurations and precast beam and slab deck construction. Following comparative cost studies, which also involved careful consideration of access to the site, location of the piers and abutments in relation to the river, the topography and the geology, the incrementally launched viaduct was selected as the preferred structural form, and approved by the Client.

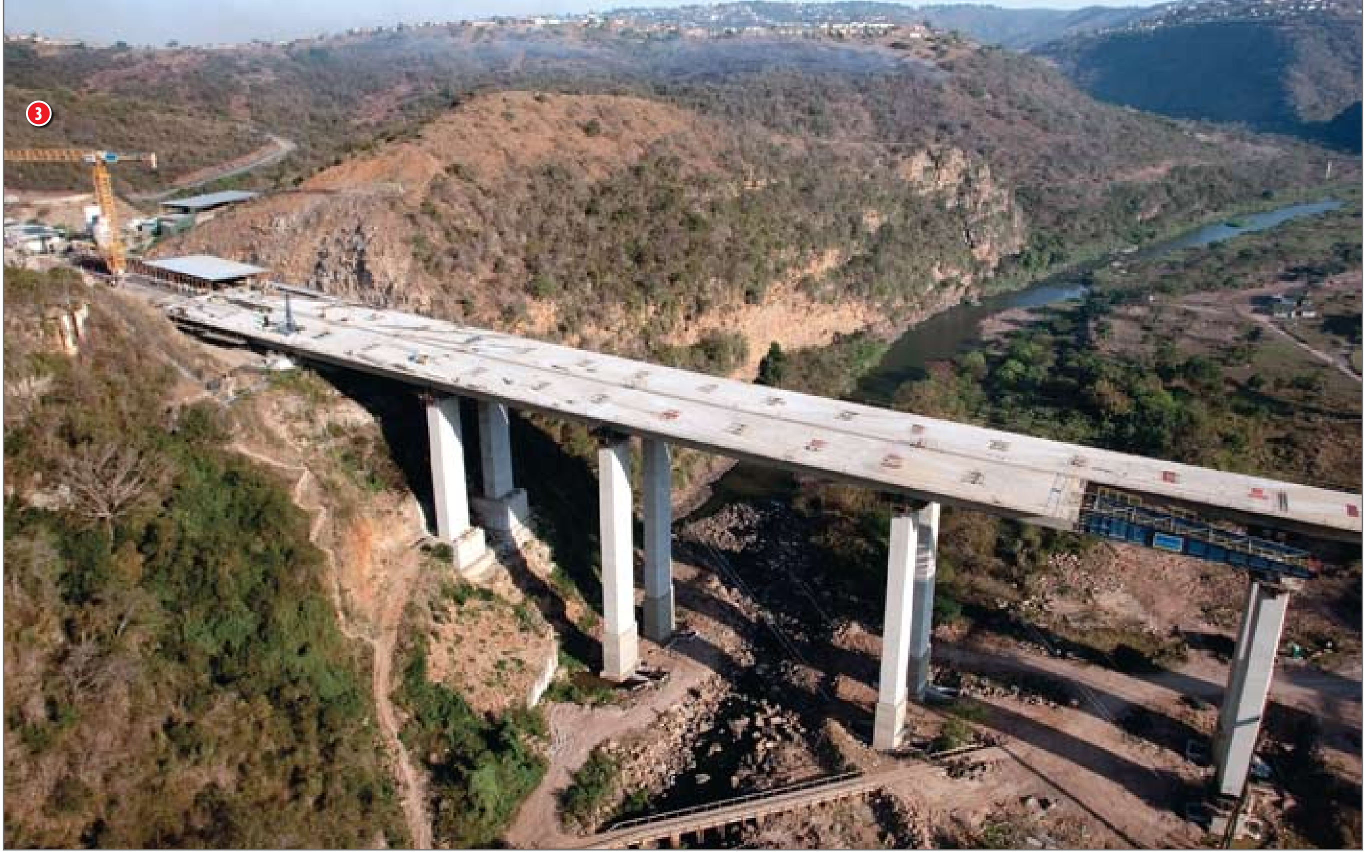
Whereas the difficulties and risks of launching the large decks down such a steep gradient from the higher eastern abutment were recognised from the beginning, this option was preferred because of the hard sandstone foundations available to support the east launch abutment and the work area behind the abutment.

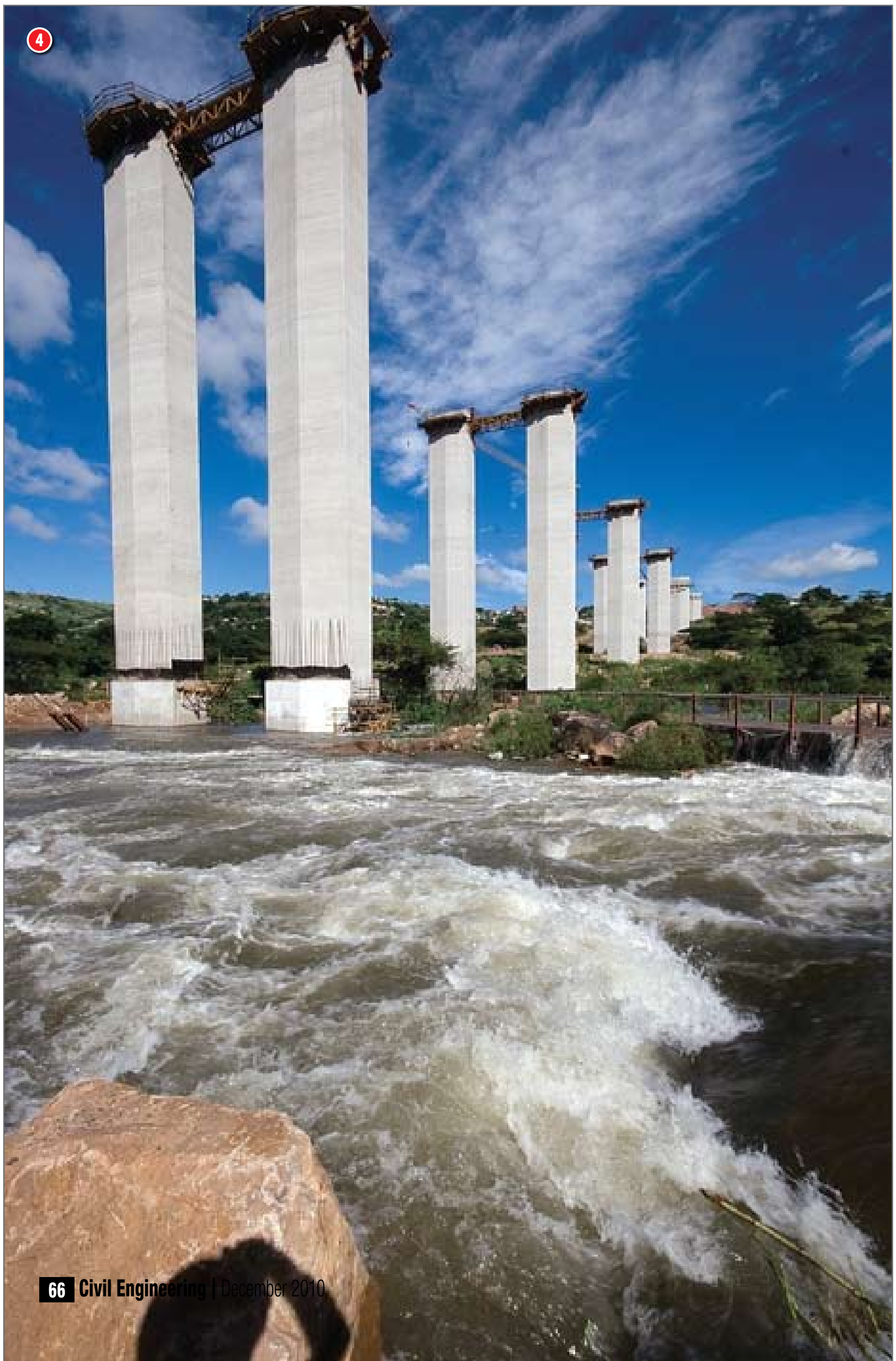
The alternative of launching uphill from the west abutment was not favoured, because of the need to construct large and costly support works through the embankment behind the abutment, in order to eliminate settlement problems during launching.

INGENUITY, ORIGINALITY AND INNOVATION – PLANNING AND DESIGN

In the years from 1981 when the first incrementally launched bridge was constructed in South Africa, this type of construction has become more prevalent, although not generally on the scale of the Mgeni Viaduct. The particular constraints of this project have tested the design team.

The first innovation which SSI brought to the project was a reconsideration of the original proposed route location. The proposed alignment of the road was intended to minimise the scale of the structure required to cross the Mgeni River. In achieving this, the length of the route was compromised. SSI proposed an alternative which reduced the travel distance between Duffs Road and New Germany by 1,4 km. An economic study showed clearly that the regional economic benefit of reduced travel times and cost far outweighed the additional construction cost. The





3 Span 4 launch under way
4 Columns for Africa!
5 Rockfall mitigation measures

Client accepted the proposal, and work proceeded with the final design. The challenge which came with the new alignment was now a significant structure 45 metres above the Mgeni River.

The geometric constraints of working in the difficult topography of KwaZulu-Natal required unusual geometric solutions, as will be seen below.

The bridge superstructure is founded on spread footings and where the piers are located in the river channel and flood plain they are anchored into bedrock with dowels. The piers are single hollow structures with a constant wall thickness, constructed by sliding. The need for a more massive design on the tallest piers was obviated by staying the piers with pre-stressing strands to manage the horizontal loads imposed by the deck as it was jacked across the pier. The strands were anchored to the base of the adjacent piers and through the top of the pier. Prior to the launching operation, the top of the piers were pre-deflected to calculated offsets to manage the imposed forces. In addition, back stays were provided to cater for the eventuality that the deck would have to be retracted. In the final scenario, after all pre-stressing was complete, the piers were allowed to return to their natural position. This is a complex operation requiring painstaking measurement and control.

The casting yard was at a gradient of approximately 9%. The circular curve was dealt with by providing each pier with temporary bearings at the correct tangent angle. The launching force at that grade was nominal, but care had to be taken to ensure that the deck was held from sliding under its own mass. This is described in more detail below under "Unusual Construction Methods".

Because of the possibility of having to retract the deck, planning had to consider the maximum 10 500 kN force necessary to achieve this. The uncertain geology of the rock face required rock anchors to be installed to counter this force. Rock slope protection measures were planned to ensure the stability of the rock faces above the abutment. This comprised the installation of rock anchors and draped mesh.

BUDGETARY COMPLIANCE

The cost of the project as tendered was R151,9 m, excluding escalation and VAT. During the construction of the launch abutment, shear zones were encountered in the sandstone rock which required modification to the rock anchors to retain the deck during the launch process.

Each anchor was split into two, entering the hillside at different angles to ensure stability. With this amendment, increasing the anchoring force was unnecessary.

UNUSUAL CONSTRUCTION METHODS

Launching a deck on a 9% downward gradient offered many challenges, as the structure was unstable and inclined to move under gravity. The launching system was required to restrain the deck at 1,3 times the down slope force of the deck, assuming zero friction. The system also needed to be able to pull the deck back in the event of a bearing miss-feed with a maximum force of 10 500 kN.

This was achieved by using 3 x 350 ton hollow plunger cylinders coupled to the deck via retaining sticks installed through the box section and connected to the cylinders via 75 mm Macalloy bars. The cylinders were set up behind the left abutment with the Macalloy bars running through the abutment. The 350 ton retaining cylinders acted as the 'anchor' with the pressure release valve being set to only allow the cylinder to collapse when a force of 1,3 times the down slope force of the deck was applied to the cylinder. Thus the weight of the deck on its own would not collapse the cylinder, so the deck did not move. These were the largest cylinders made by Enerpac to date.

In order to launch the deck it was then pulled forward by three 150 ton pulling cylinders, coupled to the deck via pulling sticks and 50 mm Macalloy bars. When the pulling cylinders were extended, the force of the pulling cylinders plus the down slope weight of the deck were enough to collapse the 350 ton retaining cylinders and overcome the friction, and the deck moved forward. The deck was thus moved in a safe and controlled manner, and the launch could be halted at any stage by stopping the extension of the pulling cylinder. This safety feature was critical because, in the event of a loss of power or pressure, the deck would not move on its own as the 'anchor' would remain in place.

Each movement advanced the deck by 750 mm before the cylinders were reset for the next sequence. The load on the retaining cylinders was transferred to the transfer cylinders at the end of each cycle, allowing the retaining cylinders to be extended. The deck was then locked off on the retaining cylinders again, the transfer cylinders were collapsed and the deck was launched again.

The launching system was controlled from a central computerised control panel where pressure parameters for the retaining and pulling cylinders could be set. This allowed the launch controller

6 A telephoto shot down the centre line of the Mgeni Viaduct

to set the system to shut down if the anticipated launch force required for launching of that segment was exceeded. This could have occurred if a bearing had been fed in upside down or an obstruction encountered.

The system could be operated in manual or automatic mode, with the automatic cycle making use of electronic sensors in the hydraulic cylinders that sent a signal to the control panel when each movement in the launch cycle had been completed. The release pressure for the retaining cylinder was set with a manual pressure release valve and the cylinder pressures could be read off dial gauges on the valve block, or off the control panel.

The launching system also included emergency switches on all the piers that were linked to clinometers installed on the four highest piers. The clinometers were equipped with electronic sensors which automatically shut the system down if the pier deflects beyond the stipulated tolerance.

MODIFICATIONS TO FACILITATE THE LAUNCH

Due to the high launch loads imposed on the box section through the pull sticks, the deck and soffit were required to be modified. The area around the pulling and retaining stick holes was thickened and additional steel reinforcing installed to cater for the launch loads. The thickening gave the pull/retaining sticks a larger bearing area on the soffit. The steel arrangement was then re-detailed to include the original design steel to facilitate easier and faster construction. As the deck grew longer and the launch loads increased, the steel was increased to cater for the increasing loads. These holes were then filled in after the segment had been launched.

The pull/retaining cylinders kick against the left abutment and sleeves were left in the abutment to allow the Macalloy bars to pass through. During the construction of the left abutment foundation it was found that a fault line ran through the centre of the abutment. A possible slip was overcome by installing additional ground anchors at different angles 16 m into the rock face. Additional sleeves were left in the abutment in case any of the ground anchors failed. Fortunately none of the additional sleeves were required.

CONSTRUCTION

The casting area was situated in a cutting and the rest of the establishment for the construction of the deck on the adjacent fill which made for a very congested site. The limited storage area made the scheduling of stock delivery and control critical, as not much could be stored on site.

The decks were launched simultaneously with segments being constructed in a cycle time of 12 to 14 days. The concrete was batched on site using a karoo batcher and placed using 2 cubic meter buckets. The box sections were cast in three sections, first placing the soffit, then the webs and finally the deck. Due to the high cement content and summer temperatures in Durban in excess of 32 degrees Celsius the concrete was required to be placed below 30 degrees Celsius. This was achieved by cooling the water to 1 degree Celsius and keeping the aggregates under insulated roofing. The 19 mm stone was kept wet using sprinklers to reduce its temperature and ice was on hand in a freezer container if required.

A strength of 35 MPa was achieved in 36 hours before the concentric prestressing was done. Cubes were match-cured on the deck under insulated boxes to get an indication of the actual strength of the element, while an onsite lab cured cubes in curing tanks for quality control purposes.

The steel was prefixed outside the shutter form and rolled into place once the previous segment had been launched. The casting bay was constructed on the radius of the vertical curve with a dip of 25 mm over the 25 m segment. The skid beam was set up to within a 1 mm tolerance and the formwork was raised and lowered on 100 ton jacks. No settlement was experienced as the casting bay foundations were constructed on the bedrock in the cutting.

RESPONSIBILITY CARRIED BY THE ENGINEER

The responsibilities of the consulting engineer extend throughout the entire life cycles of bridge structures. In this instance it was important to ensure that the structure would not only meet the conventional goals of adequate strength, long-term durability and economy, including beneficial utility, but that sufficient attention was paid to safety and the minimisation of physical and financial risk before and during the construction process.

Considerable effort was therefore applied to the design of the structure and the temporary works by the consulting engineers and the contractors jointly in the interests of economy and safety. Particular attention was paid to the design and installation of fail-safe mechanisms required during the process of launching, supplemented by ongoing checks, inspections and verification procedures. The successful completion of the structure without significant mishap is testament to the success of these efforts.

The quality of the materials and workmanship were systematically checked by the consultant's construction monitoring team throughout the construction period in the interests of ensuring the long-term durability of the structure.

ENVIRONMENTAL

The natural beauty of the bridge setting has been the inspiration for exceptional attention to the environment. The designers minimised the impact that the location of the substructure would have on the Mgeni River, and site staff respected the requirements of the contract which imposed heavy fines for violations of environmental requirements. The environment was a recurring theme during daily toolbox talks.

Specific interventions were the relocation of indigenous trees and the recording and reinstatement of the riverine environment. Numerous audits were carried out and a clean bill of health was obtained.

RESPONSIVE TO THE NEEDS OF THE CLIENT AND COMMUNITY

In consultation with the Client it was determined that the labour force would be drawn predominantly from the community. This is probably one of the real success stories of the project. As part of the P577 project, a training centre was established which provided construction-related skills training to the local community who were then in a position to be employed by the contractors engaged in the construction of P577. During the construction of the Mgeni Viaduct the contractor was, through the Project Liaison Committee, able to recruit semi-skilled employees from this pool of trainees. The contractor employed 350 local community members during the construction of the Mgeni Viaduct. Many of these people are now on the permanent staff of the contractor and two are now being sponsored through university. ☐