Gautrain Viaduct V5c

GAUTRAIN VIADUCT V5c

COMMENDATION – Technical Excellence category

KEY PLAYERS

Client Gauteng Provincial Government
Professional Team Bombela Civils Joint Venture with Aurecon as the designer
Main Contractors Bombela Civils Joint Venture
Major Subcontractors and Suppliers
Dura Soletanche Bachy Geomechanic Africa JV, Franki, VSL

INTRODUCTION

The Gautrain Project is a dedicated heavy-rail line which supports the operation of a fast transit system capable of operating at speeds of 160 km/h. The project is divided into a series of reference sections and design packages. The Bombela Civils Joint Venture (BCJV) is the contractor responsible for the design and construction of the civil infrastructure associated with the project. Aurecon was awarded Detail Design Package 6A (DD6A). The main distinguishing aspect of this design package is Viaduct V5c.

Viaduct V5c, the single longest viaduct on the project, is located on the route through Centurion, south of Pretoria. The route through the Centurion CBD is fairly congested with existing infrastructure, and situated on complex dolomite geology. The elevated Centurion Station platforms were constructed on top of five spans of this viaduct.

Unique engineering design and innovative solutions were required to overcome construction challenges associated with Viaduct V5c. These solutions distinguish this viaduct from the others on the Gautrain project, even though it has a similar appearance to the standardised viaducts. These unique challenges are:

- the design and construction of foundations on a geotechnical strata that is well-known for the sinkhole risk associated with the dolomite bedrock, and
- the fact that the majority of the pier foundations are not founded on bedrock, which results in possible settlement and/or movement of the structure – this has a specific influence on the structural design of both the sub- and superstructure.

DESCRIPTION OF STRUCTURE

General

Viaduct V5c is a 3,2 km long match-cast segmental constructed box girder bridge which consists of 67 simply supported spans. Five spans of the Viaduct also accommodate the elevated station platforms of the Centurion Station. The Viaduct extends from the N1 at the John Vorster interchange to the N14 Jean Avenue interchange. At these interchanges, the Viaduct joins Viaduct V5b and V5d (which were balanced cantilever constructions and designed by other consultants). The track level varies from approximately 7 m to 22 m above natural ground level. The longitudinal grade varies from 0,5% to 4%. The horizontal alignment starts on a left hand curve with a radius of 1 170 m leading to Centurion Station, where the track is straight, followed by a right-hand curve with a radius of 1 600 m thereafter.

Superstructure

The deck comprises a series of simply supported spans of 44 m, 50 m and 56 m in length. Span lengths are arranged to optimise the structural efficiency and to avoid the obstacles of infrastructure encountered along the route.

The deck is a prestressed (internal and external post-tensioning), trapezoidal concrete box with side cantilevers. The deck is constructed as a series of precast segments temporarily supported by a launching girder or gantry. The Viaduct segments are typically 10,1 m wide and 3,5 m deep, with lengths varying from 2,1 m to 2,8 m. Each deck is supported on two bearings at each pier, which prevent transverse movement.

The simply-supported spans are longitudinally fixed at one pier and longitudinally free at the other.

Substructure

Viaduct V5c is supported on 66 reinforced concrete piers. Each pier comprises a 3 m x 4 m rectangular hollow stem with 0,3 m thick walls and a solid pier head and base to suit the founding solution. The pier heights vary between 6,75 m and 23 m, which is achieved by construction of a standard pier head (3 250 mm), a number of standard construction lifts (4 000 mm) and a correction construction lift (which varies from 2 000 mm to 6 000 mm in 500 mm increments).

1 Location of Viaduct V5c in Centurion
2 Viaduct segment
3 Typical pier
4 Struts supporting the elevated Centurion Station

The standardisation of the pier head and standard 4 000 mm lifts allowed reinforcement cages to be prefabricated. This was advantageous considering the tight construction programme.

Centurion Station

The majority of the Centurion Station buildings (ticket offices and foyer) are located underneath the viaduct with elevators providing access to the station platforms above. The standard viaduct segments were modified by the addition of external propped extensions (precast struts) to the cantilevers. These provide support to the precast station platforms, parapets and station canopy. Precast struts are connected to the modified segment using a combination of transverse prestressing and a lower steel-pinned connection.

The precast platform panels comprise a combination of panels fixed (in-situ stitch) to the struts, and fill-in or drop-in panels between fixed panels. These platform panels are not only designed for the associated commuter loading, but also accommodate the canopy supports and parapets.

5 Launching of girder

6 Placement of segment on launching girder

Foundation types

Four different foundation types were used to support Viaduct V5c, mainly due to construction restraints and the complex nature of the geology associated with the Viaduct. A comprehensive discussion will follow further down with regard to the geological conditions, geotechnical design and foundation types.

Existing infrastructure and services

The major part of the Viaduct V5c route is urbanised and congested with existing infrastructure. A large number of existing services had to be moved or relocated to enable works for the viaduct construction. These services included telecommunication, bulk water and sewerage, power supply, road infrastructure and buildings, to name but a few.

CONSTRUCTION METHODS

The superstructure for Viaduct V5c was constructed using the match-cast segmental construction method. It is widely used for the construction of long viaducts in other parts of the world. The Gautrain Project was the first project to implement this method of construction in South Africa.

This method was considered economically viable on this project because there are a number of viaducts on the project where the launching girder could be used. The initial costs associated with the expensive launching girder require a substantial length of viaduct to ensure feasibility of the method. Furthermore, this method of construction is conducive to an increased construction rate:

- The precast deck segments allowed construction of the superstructure to commence before the actual completion of the piers.
- The repetitive nature of the precast activities and span erection facilitated higher quality of workmanship and increased production rates.
- The use of a launching girder minimised disruption to the movement of traffic below the construction works in the highly urbanised environment of Centurion.

Briefly, the segmental construction process entailed the following:

- Construction of foundations and substructure at each pier position.
- Matching the casting of precast segments at a remote precast yard, as well as the transportation of the 40 t segments to the span erection site.
- Erection of the under-slung gantry on pre-fitted pier brackets. This gantry was used as a launching girder at each span.
- The launching girder was loaded with the required number of (matching) segments and the joints were then prepared with an epoxy. Epoxy between joints is primarily for the corrosion protection of the internal prestressing strands and does not have a structural function. Segments are temporarily prestressed together so that 1 MPa stress is achieved at each segment joint.
- As per the design, the first stage permanent external and/or internal tendons needed to be installed and stressed. During this operation, the loading of the superstructure systematically shifted from the launching girder to the temporary bearings.
- At final load transfer to the bearings, the launching girder was moved forward to the next span position.
- After the launching girder had been moved, the span was finished to comply with the additional stressing requirement, deck furniture and ultimately, the ballast and deck.

DESIGN CHALLENGES

General

Aurecon's client required an optimum design within the constraints of the applicable codes. A consultation process for the optimisation of all design elements was followed, which included various design iterations and liaison with the construction team and other sub-consultants on the project. This process was not necessarily unique to the general design of Viaduct V5c. However, the unique challenge was the foundations for the optimisation of the 66 piers, each with different subsoil conditions on the dolomite strata, and the effect of the foundations on the entire viaduct structure.

Design criteria and loading

Viaduct V5c is designed according to the Eurocode, which was considered more suitable for the precast segmental construction than the traditional bridge design code used in South Africa (TMH7). The Eurocode has a number of advantages and disadvantages. The advantage is that it deals with a broader variety of train loadings, realistic load combinations and gives more freedom to the designer to base the design on first principles.

However, a disadvantage of this code is that it is dependent on National Annexes for design particulars specific to local conditions.

The initial stages of the design process involved the establishment of design criteria for the design of the viaducts on the project. Standardisations of the design process across all viaducts played an important part in the financial feasibility of the segmental construction. The design criteria captured the main features of the applicable Eurocode and provided the 'missing' details that would normally have been provided in the National Annexure.

Geotechnical design

Background

The route of the Gautrain is situated on the extensively weathered Transvaal dolomites (Monté Christo Formation) which are approximately 220 million years old. A characteristic of these dolomite formations is that they contain layers of chert and impurities, such as very light and highly compressible wad (an acronym derived from *weathered altered dolomite*). These layers have a major impact on the engineering behaviour of the stratum.

Over geological time, the dissolution of calcium carbonate rock by small amounts of carbonic acid in the groundwater gives rise to complex three-dimensional passages and caves within the bedrock. Over the design life of the structure, these caves and passages may result in the development of sinkholes and/or dolines. A sinkhole is a large hole with vertical slopes opening at the surface, while a doline is a local area settlement of the soil.

Furthermore, the bedrock profile is highly undulating, resulting in extreme variations with regard to the overburden thickness and deep valleys between bedrock pinnacles. Variations of 30 m or more were encountered over distances of 3 m during the ground investigation for Viaduct V5c.

The dolomite bedrock may be classified as extremely hard rock (uni-axial compressive strengths of 300 MPa or more). In contrast to the extremely hard dolomite bedrock the highly weathered overburden, or wad, may only have stiffness in the order of 5 to 10 MPa.

The settlement and deflection predictions of the substructure were of the essence to ensure that track standards are maintained at all times.

Geotechnical investigations and measures

Extensive geotechnical investigations were conducted at each pier position, which typically included:

- Preliminary investigation comprising rotary percussion boreholes with Jean-Lutz parameter recording, as well as borehole radar to establish voidedness or occurrence of boulders and test pits.
- Specialised investigations comprising core drilling and pressure meter testing in non-dolomitic layers.
- Full-scale loading to verify and calibrate soil stiffness assumptions. This comprised the placement of 2 m x 2 m x 1 m concrete blocks on a 20 m x 20 m area and 10 m height.
- Assessment of grouting boreholes to verify the original design assumptions of bedrock variation and the occurrence of floaters.

Foundation design

Although a number of foundation solutions were used for Viaduct V5c, two specific aspects had to be addressed or mitigated as part of the design process for each pier location. These were the effects of an extreme sinkhole on all the structural elements and the settlement/deflections of the substructure.

Floating/raft foundations (total of 46)

The preliminary design for the Viaduct was done by other consultants in the beginning of 2006, which only included piles to rock or shaft foundations. The above-mentioned geological composition makes the installation of piles to rock or spread footings on rock extremely difficult and expensive.

Aurecon initially proposed a 'floating foundation' solution (piled raft or raft foundation not founded on rock). This proposal was then further developed and refined in conjunction with BCJV.

The possibility of settlement of a floating foundation on dolomite bedrock and the subsequent effect on the rail tolerances required accurate settlement predictions. However, the adequate full-scale settlement data did not exist and the need for a full-scale load test was recommended. Although a full-scale load test to determine the possible settlement is not normally done, it had two major advantages for the BCJV:

- Testing the expected settlements enabled them to calibrate settlement calculations.
- It enabled the preloading of sub-soil material to improve material properties and reduce predicted settlements.

A further full-scale test was carried out at Pier P26 (where the pier was loaded with the full expected loading of the completed viaduct and train) after completion of the pile cap to verify the settlement calculations.

These foundations comprise a 12 m x 12 m raft or pile cap, as well as 20 number 600 mm diameter percussion drilled piles. The piles were either 10 m or 15 m in length, and the majority of piers are founded on this type of foundation. As the foundation is not founded directly on rock, they are considered to be 'floating'. The sinkhole load case was mitigated with compaction grout injection or void filling (20 m x 20 m area) at the pier locations. The objective of this procedure was to fill existing voids in the bedrock and overburden.

The design is therefore based on the assumption that a sinkhole will not form in the void filled area and the 20 m x 20 m block will be stable should a sinkhole form next to this area. BCJV verified this assumption with finite element modelling and calculations by other consultants.

Settlement results for the full-scale loading at each pier were analysed. Depending on these results and the borehole logs, either rafts or piled rafts (with 10 m or 15 m piles) were implemented. Piles were introduced to the raft solution to reduce settlements where the raft foundation was insufficient. Pier 26 was test-loaded to the actual working load of the viaduct which confirmed the assumptions.

Piles to rock (total of 7)

At a number of locations, the subsoil conditions limited access for equipment (next to some of the main access roads) and availability of construction equipment made the installation of piles to rock more suitable than a raft foundation.

Large diameter pile foundations comprised four or six number 1,3 m diameter piles (typically 25 m long), underneath a 7,2 m x 7,2 m pile cap. The extreme sinkhole risk and deflection aspects were considered as part of the conventional design of the pile foundations. It is important to note that the sinkhole load cases were considered critical and resulted in a substantial increase in reinforcement quantities in the piles.

Shaft foundations (total of 7)
Shaft foundations were only installed where the founding depth was above the water table, access restraints or limited space existed but construction equipment was available. The shaft foundation comprises a 7 m diameter shaft with 500 mm thick walls, filled with compacted soil. Again, the extreme sinkhole risk and deflection aspects were considered as part of the conventional design of the shaft foundations. The shaft foundation is considered a very effective solution to mitigate the effect of a sinkhole on the structure.

Spreadfootings (total of 6)
Spreadfootings were considered feasible at locations with overburden less than 5 m and a fairly horizontal or predictable bedrock profile. Typically, these footings were 6 m x 6 m square founded directly on the bedrock.

Structural design

General

The structural design of the typical viaduct included:

- Design of a conventional post-tensioned concrete deck and the reinforced concrete piers.
- Generation of segment catalogues as shop documents for the construction of the superstructure. These catalogues included all the relevant details pertaining to the span- and segment geometry, inserts, prestressing and reinforcement details.
- Special provisions for the segmental construction method and other construction related inserts, which included the accommodation of temporary brackets on the piers to accommodate the launching girder.

Unique Viaduct V5c design

In addition to the general viaduct design requirements and as a result of the unique founding solutions, the design of Viaduct V5c was influenced by the soil-structure interaction and the rail-structure interaction. The fact that the subsoil conditions necessitated the implementation of mainly floating foundations and the installation of a continuous welded rail on top of the structure, affected the overall design approach and methodology.

The floating/raft foundations resulted in much larger structural movements than piers founded on rock. These structural movements have a direct influence on the stresses in the structure as well as in the rail. The behaviour of the complete system, including the foundation conditions, under longitudinal traction/braking and temperature effects, is essential to the overall structural performance of the viaduct.

The effect of the extreme sinkhole event on the piers founded on rock is significant to the structural performance on the foundation and the overall integrity of the viaduct. These piers and associated foundations were therefore designed to accommodate the extreme sinkhole event without jeopardising the structural preference of the viaduct. Aurecon's detail design team analysed these complicated effects which resulted in an optimum solution that complies with the design codes and satisfied BCJV's requirements.

CONCLUSION

The Gautrain project plays an important part in the economic development of the Gauteng Province. The route of this rapid-rail project passes through the congested Centurion urban area with existing infrastructure and is situated on complex dolomite geology.

Although a number of similar viaducts exist on the project, Viaduct V5c is the single longest viaduct on the project. The viaduct has a unique design and overcame exceptional construction challenges. These included the design and construction of foundations on a geotechnical stratum that is well-known for the sinkhole risk associated with the dolomite bedrock, as well as the majority of the pier foundations that were not founded on bedrock, resulting in the provision for possible movement of the structure. ◻

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Source:
http://www.saice.org.za/downloads/monthly_publications/2010/2010-Civil-Engineering-dec/#/0