Emergency repair of Bridge B421

over the Olifants River after flood damage

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INTRODUCTION AND BACKGROUND

Bridge B421 is located on the R555 at km 5.03 on Section 01E between Witbank (now known as eMalahleni) and Middelburg in the province of Mpumalanga. It is a four-span bridge, with each span comprising a simply supported voided slab. The main and back spans are 15.85 m and 16.15 m respectively. The deck is supported on elastomeric bearings and has a pressfit seal as expansion joint at all the supports. The piers are wall-type on spread footings and the abutments are wall-type closed abutments with splayed wing walls on spread footings.

Heavy rains fell during December 2010 and January 2011, resulting in a swollen Olifants River and the opening of the Witbank Dam sluice gates (upstream of the bridge) twice between 6 and 10 January 2011. The net effect of the flooding on the bridge and road was a large sinkhole in the road and the washing away of the Witbank abutment on the downstream side.

FLOOD DAMAGE TO THE OLIFANTS RIVER BRIDGE

Flood damage to Witbank abutment

The opening of the sluice gates before the inspection on 7 January caused the water level in the river to rise above the edges of the wing walls. The sudden increase in the flow height and velocity of the water resulted in a whirlpool starting on the downstream side of the Witbank abutment.

The Witbank abutment had been founded on silty sand, as was confirmed by the geotechnical investigation (discussed later in this article). The whirlpool caused the backfill material behind the wing wall to become saturated, resulting in minor scour at the back of the wing wall and below the wing wall foundation. The scouring around the wing wall foundation and the additional water pressure behind the wing wall then resulted in the wing wall footing starting to rotate forward.

The rotation of the footing caused the wing wall to rotate with the footing. The wing wall was connected to the abutment wall with dowels and a concrete shear key. The abutment wall supported the weight of the deck, resulting in the abutment wall being partially propped at the top and therefore unable to rotate with the wing wall. This resulted in additional moments and forces on the abutment wall, for which the mass concrete wall had not been designed. The additional forces and moments caused the abutment wall to break at the construction joint at mid-height (see Figure 1).

Between the first and second inspection on 10 January 2011 more heavy rains fell, necessitating the opening of the

Figure 1: Broken Witbank abutment wall

Figure 2: Failure of Witbank abutment wall

Figure 3: Another view of the broken Witbank abutment wall

dam sluice gates for a second time. This resulted in the water level rising higher than the breaking line of the abutment wall, which allowed water to flow in behind the abutment and wing wall.

The inflow behind the wing and abutment wall increased the size of the whirlpool, which in return increased the erosion behind the wing and abutment wall. This resulted in the abutment and wing wall collapsing and leaving a large sinkhole in the road (see Figures 2 and 3).

The failure of the wing wall and the Witbank abutment wall on the downstream side, up to a vertical construction joint, led to the deck being supported only by the remaining half of the Witbank abutment. This, coupled with the appearance of the sinkhole, resulted in the road being closed.

Flood damage to Middelburg abutment

The increase in water level at the Middelburg embankment resulted in the fill behind the abutment and wing wall becoming saturated. Fortunately the Middelburg abutment and wing walls are founded on rock (discussed later in this article), which prevented scour below the footing and resulted only in additional water pressure, which in turn increased the loading on the back of the abutment and wing wall.

With the wing wall designed as a cantilever and therefore free to deflect forward, it caused additional pressure on the abutment wall. As the abutment wall had been designed to support the dead weight of the deck, it was partially propped at the top and was therefore prevented from deflecting with the wing wall. This resulted in the Middelburg abutment wall cracking at the horizontal construction joint at mid-height.

INVESTIGATING POSSIBLE REPAIR SOLUTIONS

Geotechnical investigation

Investigation methodology and results

A detailed geotechnical investigation was carried out in order to determine the founding conditions and level to bedrock at the Witbank and Middelburg abutments. Six rotary core boreholes were drilled, with Standard Penetration Tests (SPTs) being carried out in the softer materials. Boreholes BH4 and BH5 were drilled at the Witbank abutment, borehole BH6 was drilled north of the failed Witbank abutment, boreholes

BH1 and BH2 were drilled at the Middelburg abutment and borehole BH3 at the Middelburg pier.

The drilling results indicated that the Middelburg abutment and eastern pier were founded on very soft to soft rock mudstone with an expected unconfined compressive strength (UCS) of 1 MPa to 10 MPa.

The Witbank abutment was founded on silty sand with an allowable bearing pressure of 100 kPa, with the bedrock located at a depth of approximately 7.5 m below the top of the existing base.

Monitoring of bridge abutments

During the geotechnical investigation phase the horizontal cracks in the centre of both abutment walls were monitored for any forward bulging to determine the stability of the walls. It was found that the Middelburg abutment wall was not bulging forward, while the Witbank abutment was bulging forward, raising concern over the long-term stability of the remaining portion of the abutment.

Investigating possible repair methods for the Witbank abutment

Remedial work under traffic conditions

The first and most important remedial action considered was to investigate whether the abutment could be repaired with the road open to traffic. To determine this, a detailed analysis of the deck in its current state (cantilevering out at the Witbank abutment and not acting as a simply-supported deck between supports), with one lane of traffic over the remaining half of the Witbank abutment wall was required.

The results of the analysis indicated that the deck was at the ultimate limit state capacity with only the dead load and would exceed the ultimate capacity if opened to traffic. The option of repairing the abutment under traffic conditions was obviously not viable and was therefore not investigated further.

Potential repair of remaining portion of the Witbank abutment

The existing abutment had been designed and constructed as a mass concrete structure. The structure was founded on a solid spread footing with no construction joints. The abutment wall had been constructed with construction joints horizontally at mid-height and two joints vertically (pour strip) at the middle of the abutment. The remaining portion of the abutment exhibited signs of distress, which indicated that the structure had essentially failed. In addition, monitoring had revealed that the structure was continuing to deform and was becoming more unstable with time.

In order to protect the upstream abutment footing against settlement and possible future scour damage, the following measures were required to stabilise the remaining upstream portion of the abutment:

Due to the depth of bedrock and the erosion that had occurred beneath the existing base, the spread footing would have to be founded on piles. In order to alleviate any differential settlement between the existing base and the adjacent newly constructed base, piles would have to be installed at the front and at the rear of the existing base. The type of pile that could be installed in front of the abutment would be restricted due to the working clearance between the top of the footing and the deck soffit. In addition, the installation of raking piles would be problematic, if not impossible. The installation of piles at the rear of the abutment would require the backfill to be removed behind the wall – in which case one could just as well remove the existing failed abutment and construct a new abutment.

Jet grouting below the spread footing, instead of installing piles, was not considered as an option, as the in-situ residual soils were not considered suitable.

The installation of diaphragm walls to support the spread footing was not considered as a suitable option due to the depth of excavation to bedrock, and instability and working clearances. The cost of establishing diaphragm wall equipment would be exorbitant and the excavation of trenches by conventional means was not an option, due to the depth of bedrock and the instability of the excavated trench walls adjacent to the river.

Soil anchors would have to be installed through the abutment wall in order to prevent the wall from deforming and bulging further. This would only have been possible on a portion of the remaining wall, as a portion of the backfill behind the abutment had either been washed away or had failed and slipped into the zone of the whirlpool.

The repair to the damaged downstream abutment and wing wall would have entailed significant excavation for the new footing adjacent to the remaining spread footing. This was not considered advisable, due to the fact that the excavation would induce additional instability to the existing spread footing, which was already showing signs of instability. The possible installation of sheet piling to safeguard the backfill was also considered problematic, as the vibration during installation could compromise the stability of the already failed abutment.

In the light of the above, and taking all the potential risks into account, it was not considered practical to try and retain the remaining portion of the abutment. The only solution that would guarantee the long-term stability of the Witbank abutment would be to:

- remove the existing failed abutment
- found the new abutment on a piled foundation with raked piles to ensure long-term stability, and
- reconstruct a new abutment.

Repair method of the Middelburg abutment

The only sign of distress caused during the flood on the Middelburg abutment was the minor opening of the horizontal crack at the construction joint at mid-height. In order to ensure the long-term stability of the wall, two rows of soil nails were installed, i.e. one row on either side of the horizontal construction joint. These dowels would ensure the lateral stability of the wall. In addition, weep-holes were installed through the abutment and wing walls to alleviate any build-up of water pressure behind the walls, should future flooding occur.

DESIGN OF THE NEW WITBANK ABUTMENT WALL

In the assessment of the design and construction method of the new Witbank abutment, the following risks and constraints where identified:

- Temporary support of the deck
- Protection of the temporary support work
- Installation of piles and its effects on the temporary support work
- Strengthening of the deck over the temporary support

Temporary support of the deck

Due to the fast-track nature of the project it was decided that the type of temporary support work and the design thereof would be the contractor's responsibility. The following information was supplied to contractors during the tender stage to assist them with the designing of the temporary support and to ensure that the deck would be safely jacked:

- The position where the jacks must lift the deck.
- 6 m clearance between the deck soffit and base slab of the temporary support.
- The temporary support work base slab to be designed for a bearing capacity of 100 kPa.
- The temporary support work platform to be designed to support a load of 3 500 kN (dead weight of the deck).
- The deck was to be constructed as a voided slab and therefore had to be jacked with a spreader beam fixed to the deck to avoid punching through the voids of the deck.
- The jacking of the bridge would have to be done in phases, and evenly, to ensure that no excessive pressure would be placed on the deck, which could result in breaking.
- Temporary supports would have to be installed between the jacks to support the deck, while jacks are removed once the jacking is complete.
- During the jacking of the deck between the phases, and during the first 24 hours after the jacking has been completed, the temporary support slab would be monitored to establish if the temporary support is stable to proceed with the demolishing of the remaining existing abutment.

Protection of the temporary support work

The construction of the new abutment meant the deck had to be supported by a temporary structure from which it could be jacked off the existing bearings. The temporary support work had to be protected from possible flooding during the construction of the new Witbank abutment by means of a cofferdam around the temporary support.

At the time of the design of the cofferdam, the peak of the rainy season had passed and the river was back to its normal flow, so it was decided that the design of the cofferdam, in terms of risk to the temporary support work, had to withstand a 1:5 year flood.

The size (height, length and width) of the cofferdam, and the materials needed to construct the cofferdam to protect and keep the temporary support platform dry and ensure the stability of the temporary support platform during the construction of the new abutment, were identified as major risks during the construction period and were therefore fully detailed on the tender and construction drawings.

Installation of the piles and its effect on the temporary support work

The position, founding level and height of the temporary support work were dictated by the founding level of the new Witbank abutment and the level of the soffit of the deck. In order to avoid future scour, and to install raking piles below the deck while temporarily supported, the founding level for the new base slab was determined to be approximately 1.5 m below the founding level of the existing abutment or approximately

2.5 m below the natural soil. This resulted in a vertical clearance of approximately 6.75 m between the existing deck soffit and the installation level of the new piles.

The position of the temporary support work was calculated to ensure that, during the excavation of the new pile cap, the vertical excavation face would not jeopardise the temporary support work should the vertical excavation face collapse. Therefore the edge of the temporary support footing had to be outside the assumed 45° angle of failure. The founding level of the base slab was chosen to be on the same level as the existing abutment footing to reduce the risk to the temporary support work when the existing abutment is demolished (see Figures 4 and 5 for a graphic and photo explanation of the above).

The installation of the piles for the new Witbank abutment was restricted by the following factors:

- A maximum rake for the front piles of 1:3
- A minimum clearance of 1.75 m between centre of piles and deck soffit
- The piles had to be socketed through the very soft rock and onto the soft rock, possibly on a sloping bedrock surface.

The above constraints precluded the use of Auger piles or Continuous Flight Auger (CFA) piles for the following reasons:

- The piling assembly would not fit within the minimum clearance.
- The stability of the sidewall of the excavated shaft could not be guaranteed.
- Difficulties were foreseen with developing the pile socket on a sloping bedrock surface while maintaining the required alignment.

The final solution was to utilise 350 mm square precast driven piles fitted with a rock shoe to ensure end bearing on at least soft rock.

The installation of the precast driven piles, however, increased the stability risk of the temporary support which would be supporting the deck while the piles were being installed. The base slab for the temporary support could be affected by the vibration and the potential expansion of the natural soil during the installation of the precast driven piles. In order to ensure the stability of the temporary support, the settlement and lateral displacement of the support slab had to be monitored during the installation of the piles.

Strengthening of the deck over the temporary support

The position of the jacks on the temporary support work altered the mechanism of the deck from being simply supported between the bearings, to having a 5 m cantilever over the support. This resulted in a hogging moment over the temporary support, as well as increased shear force, for which the deck had to be checked. The calculation showed the deck hogging moment capacity to be insufficient, but the sheer force to be adequate to resist the required capacity to safely jack the bridge off the bearings. This resulted in the deck having to be strengthened by additional reinforcement that had to be epoxied into the deck over the temporary support to enable the deck to be safely jacked and lifted off the bearings.

UPGRADING AND REHABILITATION OF BRIDGE B421

The repair to the Witbank abutment provided an opportunity for the upgrading of the bridge in terms of safety to pedestrians and other road users, and the rehabilitation of certain elements of the bridge.

The most important safety improvements to Bridge B421 were the protection of pedestrians crossing the bridge by means of a sidewalk and guardrails on the approaching ends of the bridge, and an 800 mm high standard F-shape barrier on the deck, between the sidewalk and the carriageway.

The repair and refurbishment of the existing steel handrails, the replacement of the existing expansion joint system (pressfit seal) with a new expansion joint system (Thorma joint) and spalling repairs on the deck were also carried out during the construction of the new Witbank abutment.

FAST-TRACK PROJECT

SANRAL reacted very quickly after the failure of the bridge and appointed BKS to investigate and prepare a design for the emergency repair. Throughout the

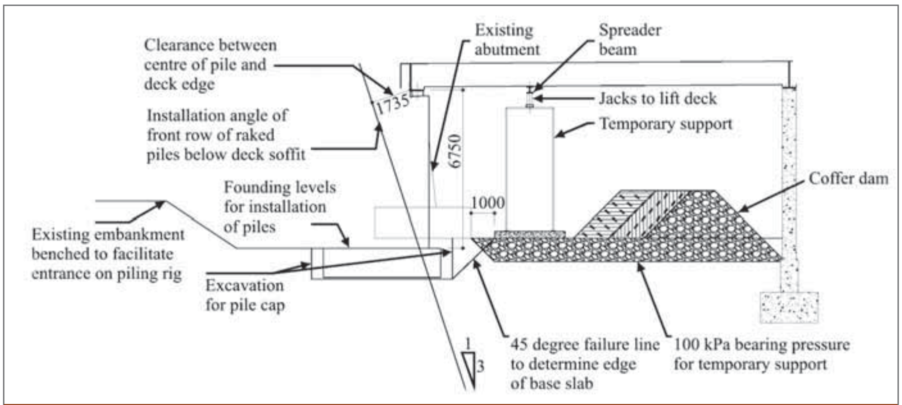

Figure 4: Graphic explanation of the restriction in the design of the new Witbank abutment

Figure 5: The installation of piles

design process SANRAL and BKS communicated daily regarding the design and progress with the tender documentation, in order to speed up the process of getting a contractor on site. This involvement from SANRAL ensured that the approval process of the tender drawings and documentation was fast-tracked. The teamwork between the client, consultant and contractor during the construction period led to the R555 being reopened to the public after only ten months of closure (see Figure 6).

CONCLUDING SUMMARY

The flood damage caused to the Witbank abutment during the 2010/2011 rainy season was beyond repair and it was therefore decided that the existing abutment had to be demolished and be replaced with a new abutment.

The design and construction of the new abutment had many restrictions and challenges, which led to the new abutment being founded approximately 2.5 m below the natural ground line on 350 mm square precast driven piles with a 1.25 m thick pile cap.

The Middelburg abutment showed signs of distress and was therefore repaired by means of two rows of soil nails, to prevent any future forward bulging of the wall.

The damage caused by the flooding of the Olifants River Bridge provided the opportunity to rehabilitate and improve the bridge in terms of user safety. These entailed minor structural repairs, new expansion joints and the installation of pedestrian barriers.

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KEY PLAYERS

Client South African National Roads Agency Limited (SANRAL)
Professional Team BKS (Pty) Ltd
Main Contractor Civilcon (Pty) Ltd

Figure 6: The newly completed Witbank abutment

Source:
http://www.saice.org.za/downloads/monthly_publications/2012/2012-Civil-Engineering-march/#/0