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The temporary plate girder railway bridge

# Vryburg Bridge Project: The design and construction of a temporary plate girder railway bridge

When a freight train hauling clinker derailed on 7 February 2022 while travelling between Vryburg and Warrenton, it caused damage to a section of railway that connects the Northern Cape to Botswana through the Ramatlabama border. The incident caused the collapse of five decks of a plate girder bridge and destroyed four masonry piers and a southern concrete abutment. A remaining cracked masonry pier and a deformed 7.01 m deck, supported between the northern abutment and the cracked pier, were later declared structurally compromised.

Constructed in the early to mid 1920s, the bridge is located approximately 20 km south of the town of Vryburg, adjacent to the N18, in the North West province of South Africa.

The bridge comprised six 7.01 m simply supported structural steel plate girder decks spanning the 42 m Droë Harts riverbed. Between the northern and southern closed-wall concrete abutments, each span was supported by 0.965 m (thick) × 3.6 m to 3.8 m (wide) masonry piers, underlain by 8.6 m (long) × 3.1 m (wide) × 1.7 m (deep) concrete foundations.

## COST BENEFIT ANALYSIS

The line closure resulting from the derailment caused an abrupt loss of revenue for Transnet. An emergency was declared to

expedite the reinstatement of the bridge and the reopening of the railway line. A cost-benefit analysis was performed considering a range of options with the aim of ensuring the rapid restoration of service.

The following options were considered:

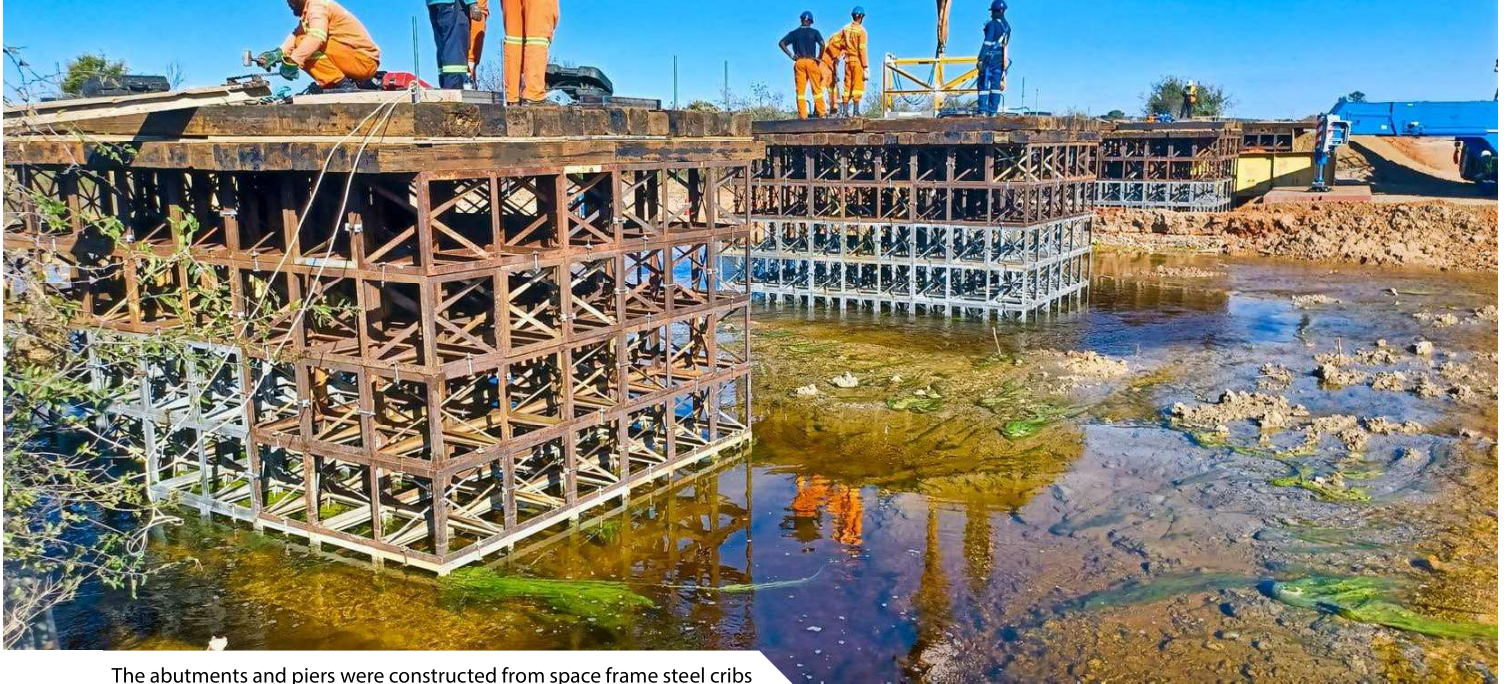
1. Option 1: Do nothing, re-direct train traffic.
2. Option 2: Permanent bridge – reinforced concrete, composite or steel deck with piers.
3. Option 3: Temporary bridge 1 – new prefabricated steel plate girder (emergency) modular bridge.
4. Option 4: Temporary bridge 2 – three-span second-hand steel plate girder bridge.

Option 1 was declared unfeasible because it would increase wagon turnaround time between commodity origin and

destination. Not only would additional pressure be exerted on the detour's existing network utilisation and resources, but customer satisfaction would be negatively impacted. Option 2 entailed complex procurement processes and a line closure lasting several months, which would cause significant revenue loss. Although the emergency modular bridge (Option 3) had a superior condition and structural capacity than Option 4, it required complex structural modifications at the northern abutment due to misalignment concerns. Option 4, considered the most cost-effective solution and yielding the quickest mean-time-to-repair, was selected and approved for construction.

The client (aided by the project management team) mobilised in-house engineers for the design of the substructure and





The abutments and piers were constructed from space frame steel cribs

superstructure of the temporary bridge. The in-house construction team (Rail Network Construction) was subsequently appointed for the erection of the temporary bridge and reinstatement of the track.

### DESIGN CONSIDERATIONS

The temporary three-span bridge comprises one 16.7 m span and two 16.2 m spans, with 1.3 m deep and 3.5 m wide structural steel plate girder decks. The entire bridge is supported by:

- Two interior piers
- One southern abutment with an adjacent mechanically stabilised earth wall (MSEW)
- An auxiliary abutment adjacent to the existing northern concrete abutment, to which the 16.7 m span was secured by chemically anchoring M20 (Gr 8.8) threaded rods with Nylon lock nuts and washers on sliding (guided) type steel bearings.

A geotechnical investigation indicated that, at shallow depth, the site was dominated by loose to medium dense, intact, clayey silty sand with medium to coarse grained gravels, where an increasing soil stiffness caused refusal of in-situ penetration tests at a shallow depth of 5 m.

The substructure comprised reinforced concrete (40 MPa) pad foundations, residing at the natural ground level, underlain by engineering layerworks consisting of 15 MPa mass concrete and a rockfill layer, intended as ground improvement measures. The pad foundations were adequate to resist 21.63 ton/axle loading (at a limited speed restriction) coupled with eccentric wheel load effects emanating

The MSEW at the southern abutment







The 16.7 m bridge deck being moved into position



Wooden sleepers were used to avoid sliding-wear behaviour and improve damping of the superstructure

from traction, braking and nosing (per the SATS Bridge Code, 1983). The foundation design philosophy encompassed the following principles:

- The underlying soil below the substructure does not experience shear failure
- The lateral stability of the superstructure is ensured
- The predicted settlement distortions are within acceptable limits.

The auxiliary and southern abutments and both piers were constructed from space frame steel cribs (0.61 m × 0.61 m × 1.83 m), fabricated using 51 mm equal leg angles and diagonal bracing bars, having a load carrying capacity of 200 kN.

Structural analysis of the superstructure was performed using state-of-the-art software. Although the primary nominal live loads were limited to 21.63 ton/axle, secondary live loads and dynamic factors, per BD 37/01: Design manual for roads and bridges (2001), were also considered. At the ultimate limit state, structural capacity analysis of the girders was performed using BS 5400-3: Code of practice for design of steel bridges (2000). At a nominal yield strength of 210 MPa for structural steel and 190 MPa for rivets, the plate girder decks and associated fasteners satisfied loading requirements.

At the serviceability limit state, deck deflections were limited to 1:1000 (per





the SATS bridge code, 1983), that is, with the central span's deck deflection limited to 16.2 mm – at an allowable axle load of 18.85 ton/axle. The allowable train speed was restricted to 15 km/h in order to:

- Reduce dynamic impact forces resulting from track and wheel irregularities
- Reduce the dynamic magnification of the static live loads

- Minimise the oscillation amplitude of the structure.

A 3.2 m (high) × 2.6 m (wide) × 7.5 m (long) retaining wall was required between the southern (crib) abutment and existing (southern) railway embankment to facilitate track transition and retain the embankment fill.

A MSEW was the most cost effective and least labour intensive option compared to conventional lateral support systems. The MSEW was constructed using cement-stabilised G2 fill, compacted to 88% relative density, with the soil reinforced using rock grid PC 200/200 – forming a 90° wrap-faced soil-reinforced wall. After being stabilised using 5% to 6% cement to prevent bulging of the wall and to improve the soil's unconfined strength, the face of the MSEW was protected to avert UV degradation of the high tensile strength composite geotextile fibres.

## CONSTRUCTION PROCESS

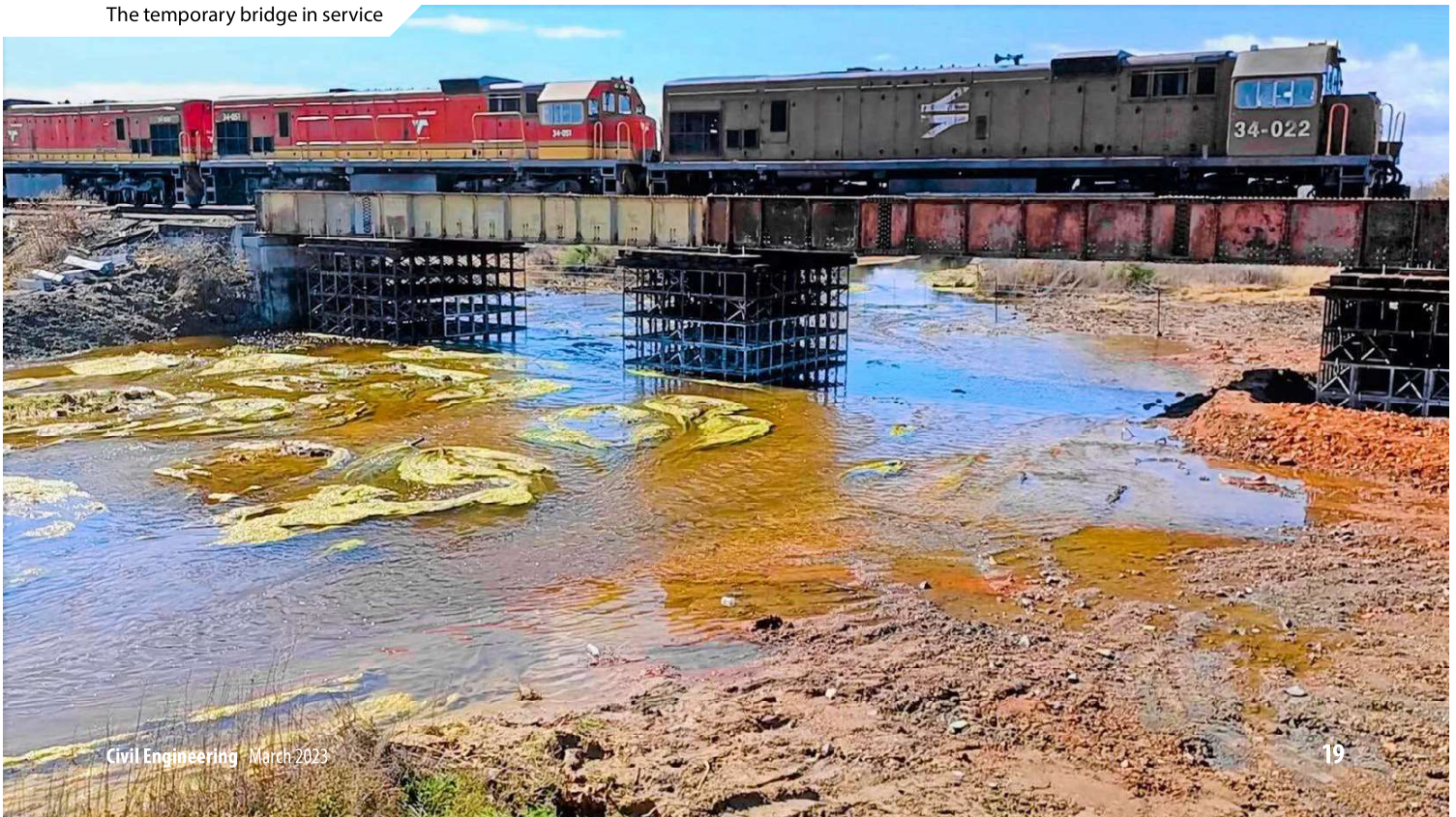
After site clearance was completed and the relevant emergency permits obtained, the area was staked out and construction began with foundation excavations for the southern abutment and southern pier, followed by river diversion which subsequently aided the foundation excavation for the northern pier and auxiliary abutment. While the foundations were being poured and undergoing curing, the assembly of steel cribs for the piers

and abutments were completed in a flat clearing 500 m south of the site.

Individual steel cribs were assembled in a staggered pattern and clamped using bolted clips to enhance stiffness and load transfer through the assembly. With all steel cribs designed at the same transverse width of 5.49 m, the longitudinal widths for the piers and auxiliary abutment were 3.66 m, while the southern abutment's design width was 1.83 m. After 48 hours of curing, each crib assembly was lowered and aligned into position (using guide ropes, slings and a large 30-ton hydraulic excavator) on each of the cured foundations before being secured with a chemical adhesive and U-shaped Y20 bars, anchored to a drilled depth of 300 mm, thus increasing the sliding resistance of the crib assembly under the effect of lateral and eccentric loads.

The deck assemblies of the three spans entailed securing 25 cross-girders to each of the 16.2 m spans and 27 cross-girders to the 16.7 m span using zinc galvanised M20 (Gr. 8.8) bolts torqued to 385 Nm. Cross-girders were typically bolted to the plate girders using an arrangement of single-welded end plates and stiffened seated angle beam end connections. Splice connections were stiffened with zinc galvanised M20 (Gr. 8.8) bolts and nuts, along the girders' flanges and webs to ensure that the

The temporary bridge in service







Benefits of the project included job creation and skills development

requirements for field-bolted moment connections were satisfied.

A rigging study conducted by Concord Cranes concluded that the installation of all three prefabricated spans required a 440 ton hydraulic crane with a minimum heavy boom length of approximately 40 m and a working radius of 28 m. This lifting operation utilised an 80 ton capacity crane hook and a four-legged sling configuration with an approximately 90° angle between diagonally opposed legs, with two slings assumed to carry the full load and the two remaining slings fulfilling the function of load balance.

To avoid sliding-wear behaviour and improve the damping of the superstructure, wooden sleepers were introduced between the steel cribs and plate girders before the girders were secured to the crib piers and abutments.

Critical challenges overcome during the project included:

- Emergency procurement of stolen bridge components and transportation of bridge components from Johannesburg and Durban to the site.
- Intermittent river diversion coupled with the risk management of an increasing flow depth utilising

*To avoid sliding-wear behaviour and improve the damping of the superstructure, wooden sleepers were introduced between the steel cribs and plate girders before the girders were secured to the crib piers and abutments.*

- compacted bund walls and 900 mm portal pipes during the foundation excavation and casting phases.
- Continuous dewatering of the foundation excavation areas before and during casting.
- Shoring of the foundation excavation walls for the northern pier and auxiliary abutment as a result of seepage effects causing localised instabilities.
- Ground improvement which helped to create a stable platform from which the crane operated, comprising compacted layers of dump rock and crushed G5 and G7 fill.
- Obtaining optimal track geometry on straight track including:
  - A profile deviation of less than 1:1000
  - A super elevation within 3 mm
  - A horizontal alignment deviation of less than 1:2000
  - A track gauge deviation no greater than 4 mm.
- Adjustment of the bridge's elevation at the existing northern concrete abutment by the introduction of a (40 MPa) reinforced concrete plinth.

### CONCLUDING REMARKS

The aim of this project was not only to minimise Transnet's revenue loss but

also to offer skills development for young civil engineers. Additional benefits of the project included job creation and training of local labour in steel fixing and associated works, formwork construction, track formation rehabilitation, and the construction of a soil-reinforced lateral support system.

As a result of strict geometric standards required by Transnet's Manual for Track Maintenance (2012), the vertical and horizontal deck alignments were achieved with discrepancies of less than 5 mm, permitting the restitution of track geometry to an optimal standard. Routine deflection monitoring, aided by a digital level of the bridge deck, is ongoing.

The challenges and complexity of a project of this nature were alleviated by:

- Competent stakeholders
  - Continuous stakeholder engagement
  - Effective project constraint management
  - A dedicated engineering team tenaciously committed to a common goal.
- Despite numerous challenges and delays, the temporary bridge was effectively erected within 47 days without any reported injuries or environmental pollution incidents. The railway line was re-opened to train traffic on 12 May 2022, 24 hours after finalising work on the bridge deck. ■

Key role players	
Client	Transnet Freight Rail (TFR) Rail Network Depot, Krugersdorp
Project management team	TFR – Office of the Chief Executive
Design team	TFR Technical Office and Rail Network & Capital Projects
Contractor	TFR Rail Network Construction