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Emergency rehabilitation of Selby interchange on M2, in Johannesburg, South Africa

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Abstract. In this paper, the retrofitting and rehabilitation of the M2 Selby interchange, on the M2 in Johannesburg, Gauteng, South Africa, is presented. After noting large shear cracks on the pier columns, the highway had to be closed down, for 10 months. The client for the project was the Johannesburg Roads Agency (JRA), the contractor was Stefanutti Stocks Civils, and the consultant was WSP. The project commenced with the design of jacking towers which were used to jack up and support the drop-in slabs. The support system was designed to be used as a kit that can be reused in future. The demolition of the piers posed some difficulties due to the small working area within the constraints of the jacked slabs, which remained in the jacked position. The piers were designed in accordance with TMH7. A key design focus was the creep calculation, due to the unique geometry of the mushroom heads. Granite aggregates were chosen to reduce the creep and the cantilever ends were precambered. The jacked slabs were lowered and aligned only at the end of the project timeline just in time for the Thorma joints and asphalt to be added before opening the bridge to the public.

1. Introduction

1.1. Scope of works

WSP Group Africa was appointed by Stefanutti Stocks to undertake the design and detailing of temporarily works steel structures (jacking towers) to support the drop-in slabs, as well as at a later stage the design and detailing of the new mushroom head piers. The bridge is situated on the M2 highway, which is an important highway for travellers within the area. A locality plan of the bridge is provided in Fig. 1. The bridge was originally inspected and large shear cracks on the pier columns were noted, and the highway was closed, and the bridge was propped.

Design works required on the project were:
- Design of jacking towers:
    - Bases
    - Steel towers
- Design of piers:
    - Pier bases
    - Pier columns
    - Mushroom head
    - Half joints
    - Infill panels

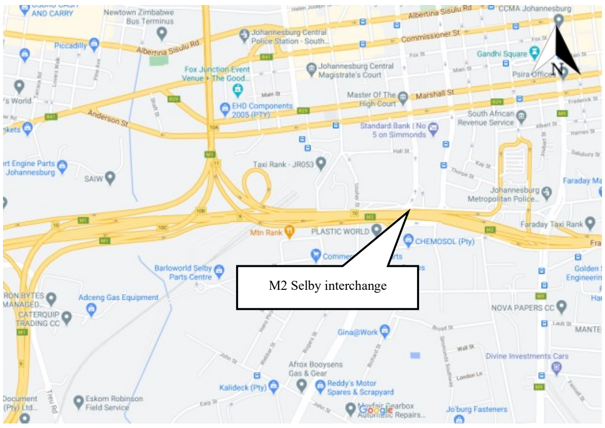

Fig. 1. Locality plan of the M2 Bridge

1.2. Background of the project

The bridges provide access to commuters in the Johannesburg (JHB) area, connecting the east and west of the JHB areas. The bridge is a multi-span simply supported structure made up of drop-in slabs supported by mushroom piers. The drop-in slabs are of reinforced concrete, and the piers are reinforced with prestressing at the top face of the mushroom heads. The repair was only required for the 4 rightmost piers next to the east abutment.

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Fig. 2. Elevation of the pier

The bridge has E80 expansion joints, and the structure is found on rock with spread footings. The typical pier dimensions are 8.0m x 12.0m x 14.0m. A typical elevation of the piers is shown below in Fig. 3.

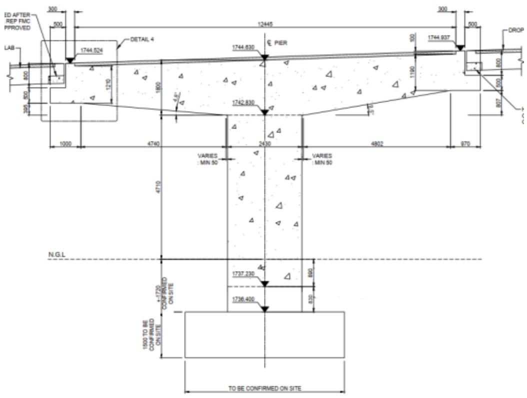

Fig. 3: Pier elevation

1.3. History of the bridge

The M2 motorway was constructed in 1948, the bridges provide access to commuters in the JHB area, connecting the east and west of JHB areas. The Selby Interchange is located just before the M1 turnoff, the bridge section with the compromised piers crossed over the Shelby Village right next to West Street.

2. Defects on the bridge

The main defects of the piers were large shear cracks as seen in Fig. 4 & Fig. 5. The cracks formed due to water entering through the top of the mushroom head and causing an alkali-silica reaction (ASR). The aggregates in the mix contain a certain form of silica which will react with alkali hydroxide in the concrete to form a gel that will swell up as it absorbs water, this will cause enough expansive pressure to damage/crack the concrete.

Fig. 4. Shear crack in the mushroom head

Fig. 5. Shear crack in the pier

3. Rehabilitation design

A detailed inspection was conducted on-site, and it was decided that temporary supports be put in place until the highway could be closed off to traffic. A photo of the temporary supports is provided in Fig. 6.

Fig. 6. Temporary supports

After the detailed assessment, the rehabilitation works required were identified.

The rehabilitation was conducted in accordance with the following applicable codes and standards:

- Code of Practice for the Design of Highway Bridges and Culverts in South Africa – TMH 7 Parts 1 & 2. (As amended in 1988).
- Code of Practice for the Design of Highway Bridges and Culverts in South Africa – TMH 7 Part 3.
- Code of Procedure for the Planning and Design of Highway and Road Structures in South Africa – February 2002.
- Design loads: NA, NB 36, and NC 30 x 5 x 40 as per the codes above.
- Eurocode 2 (1991)
- Fib Bulletin 14 – Externally bonded FRP reinforcement for RC structures.
- BS 5400 - Steel, concrete and composite bridges.

The rehabilitation design of the bridge consisted of the following key items: (i) temporary works for the jacking of the drop-in slabs; (ii) demolition of the existing piers and permanent works design.

3.1 Temporary works for the jacking of the drop-in slabs

The slabs were in good condition so there was no need to demolish them, therefore it was more efficient to reuse them. Due to the lack of space in the surrounding CBD area, there was no place to remove and store them. It was found to be more cost-effective to construct jacking towers and lift the drop-in slabs out of the way. A jacking tower is shown in Fig. 7.
The jacking towers were designed using BS5400 and the project specification. Based on the geotechnical cores and analysis the bases for the structure were found on rock. The jacking towers were designed to carry the self-weight of the structure, the drop in slabs vertical weight (360tons), 10% vertical weight as a horizontal force and 0.5kPa live load.

The limit state design method was used to determine the member sizes for the jacking towers needed to resist the moment and shear forces in the members. The design included verification of both the serviceability limit state (SLS) and the ultimate limit state (ULS).

Bases were designed using the same methods as above to resist the forces coming into the bases. The bases were cast at appropriate levels so that the jacks would sit just below the drop-in slab's soffit. A typical base can be seen below in Fig. 8.

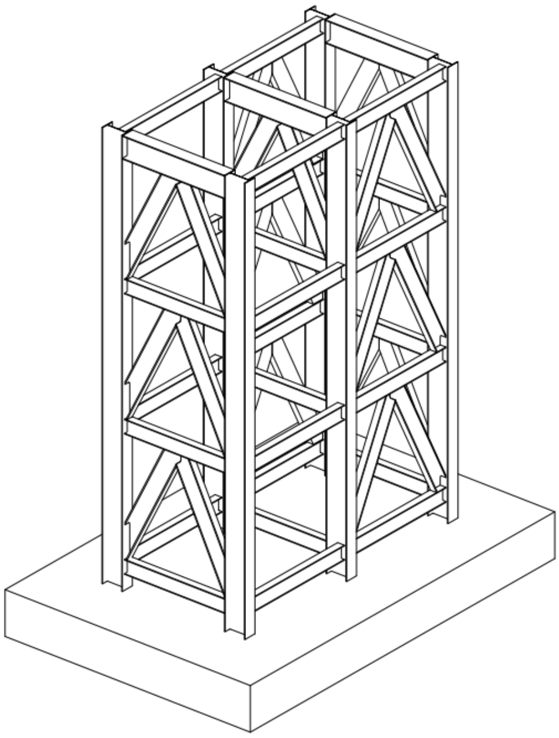

Fig. 7. Jacking tower

Fig. 8. Jacking tower base

The jacking towers were designed to be modular, this allowed for one design to fit most cases with minor additions (different legs and heights), ease of transport and to allow for future reuse. The different modular applications can be seen below in Fig. 9. Elevations of the final jacked structure can be seen in Fig. 10 showing the different modular applications.

Fig. 9. Modular applications

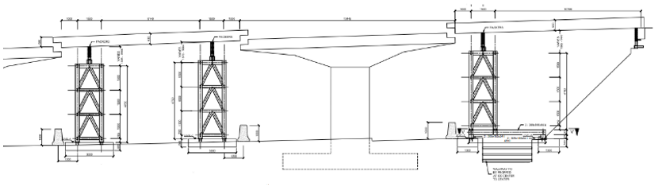

Fig. 10: Jacking tower elevation

To allow for a flat jacking surface so that there would be an even distribution of the load across the jacks, 12mm steel plates were bolted to the soffit of the drop in slabs at the jack locations and the gaps were filled with epoxy. A cross-section can be seen below the loading plate in Fig. 11.

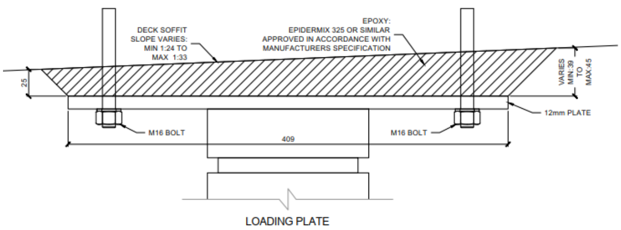

Fig. 11. Section through the loading plate

The jacking sequence was done in increments of 1.6mm with the use of packers and 1.6mm shims. A packer was placed alongside the jack and shims were added every 1.6mm, once the maximum jacking height was achieved a packer was added below the jack until the correct jacking height was achieved. The jacking process can be visualised below in Fig. 12 & Fig. 13.

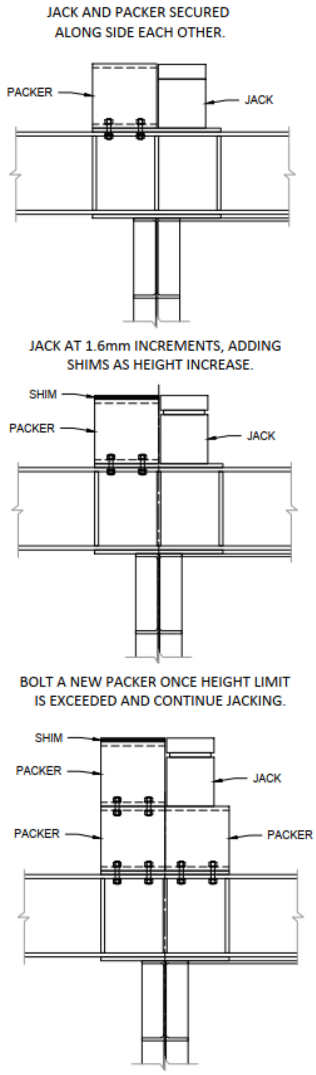

Fig. 12. Jacking sequence

Fig. 13. Jacking towers

3.2 Permanent works

The existing piers were of reinforced concrete with stressing bars at the top face of the mushroom head. Due to the time constraint to have the highway reopened and lack of stressing bars in the country at the time, an alternative design solution was proposed that would be achievable without the need for the stressing bars and would be able to be completed within the strict time frame.

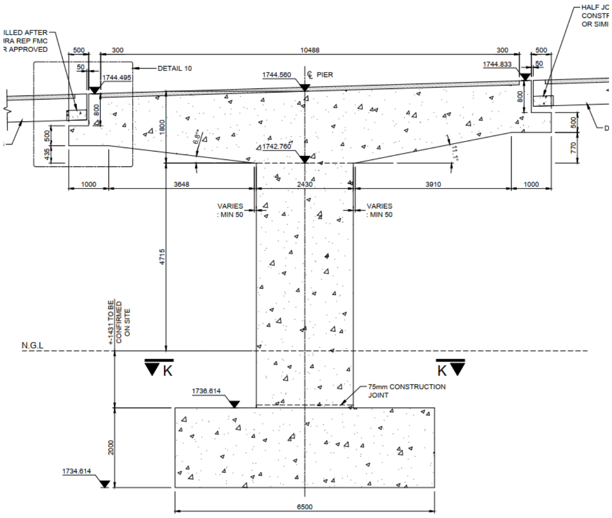

Fig. 14. Typical pier elevation

The new solution utilised the existing bases where a combination of existing starter bars, chemically anchored bars and mechanical anchors were used to dowel into the existing structure, as to not have a single plane of weakness, typical splice detail can be seen in Fig. 15.

The column and mushroom head were of reinforced concrete and the mushroom head had half joints where the existing drop-in slabs would rest on. The new piers were designed to carry the self-weight of the drop in slabs vertical weight (360tons), 12kN/m SDL and TMH7 live loading.

The limit state design method was used to determine the reinforcement required to resist the moment and shear forces in the members. The design included verification of both the serviceability limit state (SLS) and the ultimate limit state (ULS).

Due to the complexity of the structure, we had 3 different models using 3 different design packages (Midas, STRAP and SUMO (Prokon)) were utilized during the design process to compare results for each aspect.

Due to the complex geometry and thickness of the mushroom head, an additional cage was placed in the centre of the mushroom head, which can be seen in Fig. 16. This was added to provide resistance to thermal and shrinkage stresses in the structure.

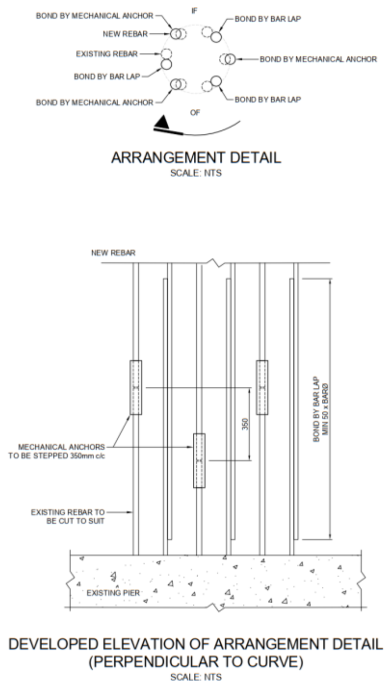

Fig. 15. Splice sequence

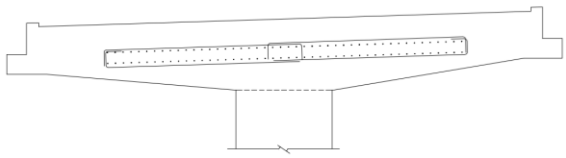

Fig. 16. Cage inside the mushroom head

Another design aspect was the half joint. This half joint would carry the weight of the drop in slabs through the use of bearings. The design was carried out with the use of the strut and tie method, by resolving forces about a crack line and using the forces in the horizontal-vertical and diagonal bars that were greater than those applied. A graphical representation of the forces can be seen in Fig 17.

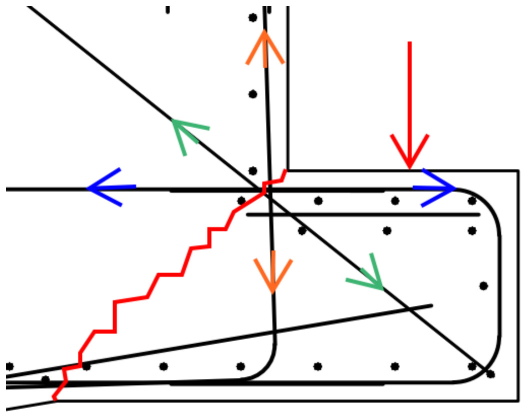

Fig 17. Half joint forces

4. Challenges and difficulties

4.1. Challenges encountered

Due to the complex geometry of this structure, creep had a large effect on the mushroom head. To accurately calculate the creep at the cantilever ends the average humidity of the area, mix design of the concrete and codes of references all need to be known. Once the information was obtained the mushroom head was modelled with the data, using strap and Midas to compare the accuracy of the results. After running the analysis, it was concluded that we would pre-chamber the cantilevers linearly from 0mm to 12mm along the cantilevered edges. A photo of the precambered formwork can be seen in Fig 18.

The aggregate type used in the mix design influenced the creep. Granites were chosen over andesite and quartzite due to their superior creep properties. The creep calculation was done according to EN1992-2 and BS8110.

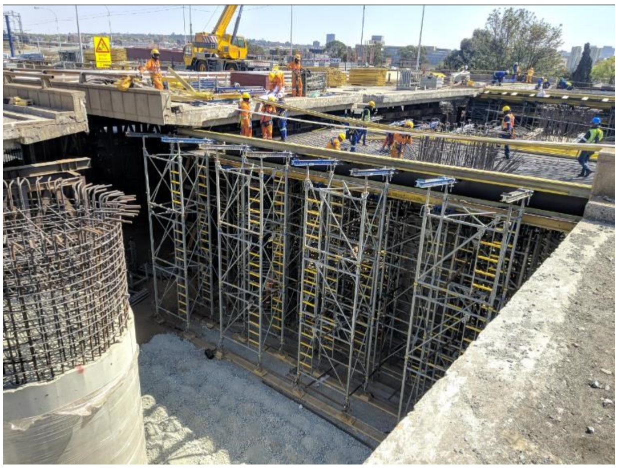

Fig 18. Mushroom head formwork

4.2.Contractual programme and dates

Another big challenge was the program and tight timeline allowed for the project. Due to the high traffic flow on the highway, it could not remain closed for a long time. This short timeframe produced a lot of pressure for the design and construction teams. 3 models were used during the design to compare results and ensure no mistakes were overlooked; all drawings were thoroughly checked to ensure no mistakes went through to the site team. The highway was closed to traffic in January 2019, the drop in slabs were lifted in April 2019, the demolitions of the existing piers were done in May 2019, the new piers were finalised in October 2019 and the highway was opened to traffic in November 2019.

5. Conclusion

After noting large shear cracks on the pier columns, the M2 highway had to be closed down, for approximately 10 months, for the safety of the road users. The project commenced with the design of jacking towers which were used to jack up and support the existing drop-in slabs that were resting on the compromised piers. The towers were designed to take the self-weight of the slabs as well as some additional live load. Demolition of the piers posed some difficulties due to the small working area within the constraints of the jacked slabs, which remained in the jacked position to make it easier to realign after the construction of the new piers. A key design focus was the creep calculation, due to the unique geometry of the mushroom heads having the cantilevering edge all around the column. Granites aggregates were chosen to reduce the creep and the cantilever ends were precambered to account for the self-weight deflection. The formwork around the edge of the mushroom head was left in as long as possible to reduce the creep. The jacked slabs were lowered and aligned only at the end of the project timeline just in time for the Thorma joints and asphalt to be added before opening the bridge to the public. The project was successfully completed within the program.