NAMOI FLOODPLAIN VIADUCT - DESIGN OF A 1 KM RAIL VIADUCT IN A REMOTE AREA FOR A 35 YEAR DESIGN LIFE

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ABSTRACT

The Boggabri Maules Creek Rail (BMCR) project will connect the existing Werris Creek to Mungindi Railway line to the existing Boggabri Coal Mine and the new Maules Creek Coal Mine.

The Railway line will provide Boggabri Coal Mine with improved logistics, efficiency and optimisation by substituting rail transport for the current road haulage of coal. The works are located approximately 15 kilometres north east of Boggabri in northwest New South Wales (NSW) and will provide the Maules Creek Coal Project with access to the rail network and ultimately the Port of Newcastle. In order to enable the proposed rail spur to connect the Mine sites, the Namoi Viaduct is required to traverse the Namoi floodplain. The Namoi floodplain is subject to frequent inundation and is fed by a permanent waterway, the Namoi River.

The Namoi River Flood Plain Viaduct comprises 5 metre high steel piers supporting a steel girder transom-top superstructure with 30m spans. A strong emphasis was placed on innovative design solutions for the viaduct that considered constructability and maintenance, reducing site based construction activities, maximising the use of pre-fabricated elements and procurement. Based on the location and surrounding environment, specific protective coatings for the steel elements were investigated to meet the design life requirements of 35 years.

INTRODUCTION

The BMCR project comprised the detailed design and construction of new rail and associated infrastructure that will connect the existing Werris Creek to Mungindi Railway line to the existing Boggabri Coal Mine and the new Maules Creek Coal Mine.

The mine is expected to sustain a potential project life in excess of 30 years with approvals to transport up to 13 Mt of coal per annum for the Maules Creek mine and an increase in production of the Boggabri Mine to 7Mt per annum.

The works are located approximately 15 kilometres north east of Boggabri in northwest NSW and will ultimately:

- Provide the Maules Creek Coal Project with access to the rail network and the Port of Newcastle.
- Provide Boggabri Coal Mine with improved logistics efficiency and optimisation by substituting rail transport for the current road haulage of coal.
- Provide significant benefits to the Narrabri and Gunnedah Regions via the generation of employment and revenue.

There are three separable portions (refer figure 1) of the BMCR project based on the ownership of each mine namely:

- Common Section – An unincorporated Joint Venture between Maules Creek Coal Pty Ltd and Boggabri Coal Pty Ltd;
- Boggabri Section – Boggabri Coal Pty Ltd; and
- Maules Creek Section – Maules Creek Coal Pty Ltd.
The subject of this paper, the Namoi Floodplain Rail Bridge, is located in the Common Section. The construction of this bridge provides for one crossing of the flood plain for both mines. The Namoi bridge was of significant importance to the project’s programme as it provides a rail connection to the remainder of the project. This would allow for delivery of longer lengths of rail to the Boggabri section and continuity in track laying and rail surfacing activities.

### Design Elements

Aurecon was engaged to provided professional services for Leighton Contractors Pty Ltd. This included preliminary design review, value engineering, and detailed design services for the BMCR project. This involved the following elements:

- 30.7 km of civil works including earthworks, track, drainage and minor structures
- a 1 km viaduct over the Namoi river and floodplain
- an underbridge at the Kambah Highway
- a major culvert structure
- haulage road deviations
- A mine access road from near the turnout junction to the Maules Creek Mine site.

### Namoi Floodplain Viaduct

In order to enable the proposed rail spur to connect the mine sites with the existing Werris Creek to Mungindi mainline and on to the Port of Newcastle, the Namoi Viaduct is required to cross the Namoi floodplain. The Namoi floodplain is subject to frequent inundation and is fed by the Namoi River.

The viaduct is approximately 1020m in length and crosses the Namoi floodplain, the existing Haul Road and Therriby Road. The soffit of the viaduct superstructure is located above the 1:2000 year Average Recurrence Interval (ARI) level to allow the bridge to remain in service during design flood events.
Design Criteria and Objectives

At the initial phase of the following Design Criteria and objectives for the viaduct were discussed and agreed with the mine client.

Objectives

- Consider safety and reliability of both operation and maintenance activities.
- Be of a high standard of quality.
- Fit with existing mine and Australian Rail Track Corporation (ARTC) operations and be suited to easy maintenance.
- Be readily constructible and support the safe construction of the project.
- Provide value for money.
- Satisfy the applicable environmental requirements, applicable standards and relevant stakeholder requirements.

Design Criteria

The Namoi Viaduct was designed based on the minimum design criteria for the project which achieved the client’s immediate and long term goals:

- Design in accordance with AS5100 – Australian Bridge Design Code
- Railway design Loading 300LA - AS5100 – Australian Bridge Design Code
- 28 Million tonnes of coal per annum
- 35 year Bridge Design Life
- Load cycles – 2.57 x 105 cycles
- Flood Loading:
  - 1 in 2000 Year Event
  - flood Level: RL 240.061 (soffit of deck is located such that it remains above the 1:2000 year ARI
  - average Flow Velocity: 3.1 m/s.

Bridge Development

The development of the type of superstructure and substructure for the viaduct underwent several evolutionary phases. Adopting advice from previous preliminary rail, hydrology and geotechnical studies.

During the value engineering phase various options were identified as possible alternatives for the super structure, substructure and piled foundations:

Value Engineering Process

A typical Value Management / Engineering process comprises the following phases:

- phase 1 – value management – idea generation
- phase 2 – value engineering – review & investigation (value engineering workshop)
- phase 3 – monitor value engineering design process
- phase 4 – value engineering – review & evaluate value engineering options
The following describes the process adopted for the Namoi Viaduct:

**Idea Generation and Initial Workshop**

Preliminary design documentation was reviewed by the Construction Manager and by the design team to identify evident areas of the existing design that could be modified or changed for potential benefit to the project. This occurred at tender stage and after project award and inception. Alternative design options were generated through a focus on design innovation, cost efficiency, ease of construction and reduction in procurement and construction duration.

The Initial Value Engineering workshop allowed all ideas generated to be tabled in an environment to allow assessment of all perceptible project impacts of a particular option and discuss all factors to ascertain the actual benefit on the project and whether the idea was worth pursuing in more detail by the project team. Any idea selected for further investigation and developed was listed on a Value Engineering Register.

**Value Engineering Workshops**

Once the initial Value Engineering options were selected, a series of Value Engineering workshops were scheduled to further investigate these ideas.

The outcome of each Value Engineering workshop was an Action List to guide the design team in producing sufficient information for costing and construction methodology review. This provided sufficient information to fully evaluate and score each option at a later stage.

**Option Development and Monitoring**

Further work was undertaken in line with the agreed Action Lists for the favourable options following the Value Engineering workshops. The output from this stage was sufficient information to present the options to the mine clients and allow a fully scored assessment of each option to be performed at a joint workshop.

**Evaluation Workshop**

At this stage the outcomes of the initial Value Engineering process were presented to the mine clients to integrate them into the Value Engineering process and facilitate decision making.

A further stage where design options were evaluated against set criteria to identify benefits or impacts to the project was undertaken with the mine clients and the construction and design team. After initial discussion, a formal evaluation procedure was undertaken. This evaluation process was in the form of a Multi-Criteria Analysis (MCA). With such an analysis each criterion is given a particular weighting, according to its impact severity or significance. Options are then scored against each criterion, with a final rating given to each option. This ensures a comprehensive review to enable selection of the best value option.

For the Namoi Viaduct the following criteria, and weighting, were agreed:

- **Construction consideration (20%)** - Construction methodology, constructability and resourcing impacts,
- **Time (15%)** - Impact of each option against the design and construction programs,
- **Cost (20%)** - Cost analysis and discussion with suppliers and subcontractors regarding pricing, availability and lead time.
- **Quality (15%)** - Consideration is given to quality of product
- **Safety (15%)** - Assessment of impacts on safety, including safety in design,
- **Environment & Community (5%)** - Review of environmental factors to determine any impact on heritage zones and local flora and fauna and environmental protection requirements.
Maintenance (5%) – Whole-of-life consideration relating to frequency of repair or replacement, maintenance costs and safe access for maintenance personnel.

Client / Stakeholder preferred (5%) - Client and stakeholders considerations

A single MCA scoring sheet was produced for each option, clearly identifying the favoured option in each case.

The workshop for the Namoi Viaduct Bridge considered the following options:

- pile design and construction – Franki piles and driven piles
- pier and substructure design and construction – precast concrete piers, in situ concrete piers, small concrete pier and steel headstock and precast pile cap
- superstructure girder material and length – 30m prestressed concrete ‘Super-T’ beams, steel plate girder, steel truss and 30m concrete L-beam
- span over Namoi River – cantilevered steel girders either side with 30m drop-in girder section, cantilevered steel girders to meet in middle of span and concrete ‘Super-T’ beams.

Findings from Workshop

The resulting preferred option for the Namoi Viaduct was a transom- topped, steel girder viaduct with 30m spans on a steel substructure, supported by driven piles. A Franki pile option alternative was also developed.

Overall Structural Design Concept

Superstructure and Furniture

The Namoi Viaduct consists of thirty four spans; each span is 30m in length equalling a total bridge length of 1020m.

A 30m span over the Namoi River was adopted:

- to minimise impacts on the existing waterway and to avoid placing a pier in the middle of the river;
- to provide a sufficient hydraulic opening so that flood levels were not adversely affected, particularly those beyond the bridge.

The steel superstructure comprises a twin steel plate girder arrangement with cross bracing at regular intervals. The rails are supported on transversely spanning transoms that are directly fixed to the top flanges of the steel girders. The 2.1m deep girders (refer to figure 2) have a...
constant flange width and thickness of 800mm and 40mm respectively with a constant web thickness of 20mm.

All of the spans are simply supported with direct support onto the intermediate piers and abutments via elastomeric bearing pads. To accommodate the design braking loads, the spans are fixed to the piers at one end of each span and are free to expand at the other.

The deck has been restrained laterally to the substructure using lateral restraint blocks cast onto the abutments and steel brackets bolted to the piers. The blocks and the brackets provide restraint against loading such as train nosing loads, earthquake loads, and lateral flood loads.

For safety purposes, a refuge is provided at approximately 20m intervals and a continuous walkway with catch screens is provided for the spans above existing roads. Two 100mm diameter galvanised steel conduits have been placed on the bridge to house services. The bridge allows for a 600mm wide maintenance access way in front of the abutments.

Substructure

The substructure for the bridge consists of two concrete cast in situ abutments, each abutment sill beam is founded on 14No. 400mm square precast concrete driven piles.

Figure 3: Prefabricated Steel Pier

These piers were of similar length steel circular hollow sections fabricated from rolled plates, with a steel headstock (refer figure 3).

By maintaining the length this enabled ease of fabrication, and ease of construction. To accommodate the different pier lengths a varying depth cast in-situ concrete stub was provided. The piers are then attached to a cast in-situ concrete pile cap via a base plate and 24 anchor bolts (refer to figure 4). The base plate required the need for gusset/stiffener plates in order to transfer the high axial loads and bending moments at the base of the pier.
Structural Modelling and Analysis

The bridge superstructure was modelled using software Strand7 and SpaceGass to obtain design actions and deflections in the superstructure due to the applied design loading.

The steel pier and headstock was modelled using Strand 7.

For the substructure, a 3-dimensional frame was modelled using SpaceGass (refer figure 5) to obtain the design actions for the piles and abutment headstock due to vertical and lateral loads from the superstructure and from road traffic collision loads. A range of horizontal linear springs were used in the model to represent the stiffness of the soil. The magnitude of the horizontal soil spring stiffness (upper/lower bound) was determined based on the pile size, spacing of vertical nodes and the horizontal subgrade modulus.
Superstructure and substructure members were sized and designed via a combination of the above mentioned software, spreadsheet sheets and hand calculations.

The design of the pile foundation was based on the geotechnical information obtained from boreholes from various stages of ground investigations.

Geotechnical design parameters were derived for the inferred ground conditions, consisting of alluvial deposits underlain by bedrock (Dacite) at varying depths and were suitable for founding driven piles. Precast piles were driven to an approximate length of 20m via the use of interlocking mechanical splices.

The ultimate end-bearing capacity and ultimate shaft friction was determined using conventional pile design approach (effective stress method). The ultimate values were factored by a geotechnical strength reduction factor ($\phi$) as per AS2159 – 1995, Piling: Design and Installation for working strengths.

**Steelwork Protective Coating**

For the steel superstructure and pier head stocks, the selection of the protective coating system for steelwork was performed with consideration of a variety of factors to achieve the most economical and most efficient technical solution. The factors considered include environmental exposure/atmospheric corrosivity; required system life; substrate and surface condition; complexity of the structure; parameters related to application; colour and appearance requirements; ease of inspection and testing; maintenance requirements; environmental constraints and costs. The choice of protective treatment for the steel elements was governed by the required bridge design life of 35 years and that the Namoi viaduct is located well away from the coast (~360 km from the Port of Newcastle).

Inorganic zinc silicate paint was one of the systems chosen and deemed acceptable for this scenario. Inorganic zinc silicate paint is known to be an effective alternative to hot dip galvanizing (HDG) for steel protection.

Durability issues were addressed using a high grade coating specification and a maintenance strategy to achieve the specified design life for the viaduct structure of 35 years. After this point the structure life may be extended through inspections and maintaining/repairing protective coats as required.

**Practicality in Fabrication**

There was significant emphasis placed on simplification of the fabrication. The procurement strategy for the steel relied on a competitive model utilising both local and international steel producers and fabricators. Effort was made to ensure an internationally available product through steel quality and common fabrication detailing.

In determining the requirements of the suppliers and construction team a number of review sessions were undertaken, including:

- constructability workshops between the construction and design teams
- tender and pricing packs supplied to fabricators with factory site visits (where possible)
- question and answer reviews between fabricators and the design team to improve ease of fabrication
- meetings and advice from the Australian Steel Institute.

Ultimately the outcomes of these discussions were incorporated into the design and formulated into a final ‘for construction’ design pack. As a result of this process of involvement the project received the following benefits:

- the time and rework with fabrication shop drawings was significantly reduced.
- productivity rates of fabrication were high.
• the fabricator was able to plan their works effectively and deliver a high quality of product (refer to figure 5 for steel pier and girders at fabrication yard).

**Figure 5: Fabrication Yard – Steel Pier Headstock and Steel Girders**

**Innovation**

To further demonstrate some initiatives that were worked with the client and the remainder of the team, detailed below are examples of how tangible benefits have been provided to the client.

<table>
<thead>
<tr>
<th>Item</th>
<th>Innovation</th>
<th>Description</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Span Configuration</td>
<td>Typical span length was increased to 30m (repetitive spans for the full length of the bridge) from preliminary 15m span configuration</td>
<td>The built up cost of the bridge is determined by the sum of the superstructure and substructure costs. The longer span provided a more cost effective solution</td>
</tr>
<tr>
<td>2</td>
<td>Full length walkway</td>
<td>Full length walkway with catch screens were provided for the spans over Therribri Road and the Haul Road.</td>
<td>The catchscreens protect motorists from the potential impact of debris falling off the coal wagons</td>
</tr>
<tr>
<td>3</td>
<td>Steel Superstructure</td>
<td>The originally Welded Beam type girders were considered to be inappropriate for rail underbridges as the connection between the flange and web plate comprises fillet welds which when subjected to high levels of transverse flexural stresses are prone to early fatigue induced failure. Hence, built-up girders were proposed instead of the standard welded section</td>
<td>The built up plate girder reduces the likelihood of failure due to fatigue as compared to off the shelf Welded Beam (WB) I sections.</td>
</tr>
<tr>
<td>4</td>
<td>Steel Pier/Headstock</td>
<td>In order to reduce formwork requirements, reduce the on-site labour component and to expedite the construction process a prefabricated steel column/headstock unit of standard sizes was developed</td>
<td>The adoption of this steel column/headstock unit provided onsite construction effort and cost savings</td>
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<tr>
<td>Item</td>
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<td>5</td>
<td>Protective Coating</td>
<td>Typically for rail underbridges in NSW designers tend to specify that the protective paint coating of steelwork shall comply with the requirements of RMS QA Specification B220 “Protective Treatment of Steelwork”. However as the proposed design life of the bridge is for 35 years an alternative cost effective protective treatment was developed.</td>
<td>The alternative protective treatment had significant cost benefits to the client.</td>
</tr>
<tr>
<td>6</td>
<td>Precast Piles</td>
<td>The original design comprised the use of cast in situ bored piles however to expedite the construction process and reduce on site time, precast piled foundations were developed.</td>
<td>The use of precast piles allowed for faster speed of construction as compared to bored piles.</td>
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**CONCLUSION**

The Namoi Viaduct provided an opportunity to explore innovative design solutions that considered constructability and maintenance, reducing site activity, maximising the use of pre-fabricated elements and procurement.

Given the significant length of the Viaduct, namely the magnitude of the piling required and number of substructures, project efficiencies were achieved in the design.

The potential opportunities in optimising the number of piles required for the bridge pivoted around being able to increase the flood plain span lengths to 30 metres and utilising prefabricated steel construction for the superstructure and substructure.

Emphasis was placed on appropriate constructability, minimising site activity, maximising prefabricated steel elements and investigating alternative steelwork protective coating systems. The project highlighted the value in meetings, value engineering workshops and reviews between designers, cost estimators and the construction team.

The success of the optioneering process can only be effectivley delivered through having all project stakeholders involved. This included an integrated approach involving the owner operator mine clients, a design team with the full range of displynary coverage and expertise and a construction project which included inputs through safety, procurement, construction methodology, and project controls. The advantage of using a simple tool such as the Multi Criteria Analysis is that it provides a team wide communication of the decision making process.

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