Einasleigh River Bridge Design and Construct Challenges (Case Study)

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Abstract  Design and Construct contracts are one of the most common contractual methods of road infrastructure construction. The principal advantage of this type of contract is that it allows the contractor to bring his construction expertise to the design process. A case study was undertaken on the replacement of Einasleigh River Bridge (North Queensland) to review all challenges faced within the design stage and construction phase. The existing bridge was extremely flood prone with seasonal flooding regularly resulting in the bridge deck being overtopped and damage to the causeway approaches. The replacement 2-lane bridge was proposed with an overall length of 416m and 5m above the existing bridge level. From the tender stage of the project, the deck unit length emerged as the governing parameter in the overall cost of the project. The design consisted of a span length with an optimum girder length and size to minimise the cost of materials. The design also provided an efficient transportation system where the 561 girders were transported 1800km from Brisbane to the site. In addition to the optimisation of the girders, geotechnical fieldwork revealed a very hard rock layer near the surface. An innovative design approach was adopted to overcome the overturning forces and stability issues. This paper addresses all the design challenges and issues that arose during construction. It also highlights the cost savings (approximately $4-5M) that that innovative design gave to the client. It also presents the advantages and disadvantages of D&C contracts experienced in this project.

Keywords: Design and Construct, Durability, Road Bridge, Precast Prestressed Deck Units, Kerb Units, Precast Reinforced Concrete Footings,
Introduction

A case study was undertaken by Opus International Consultants on the replacement of Einsleigh River Bridge (North Queensland) to review all the challenges of a Design and Construction contract as confronted in the design and construction stages. In this paper firstly an overview of the existing bridge and the proposed replacement bridge will be presented. Second, a design overview and the challenges involved during the design process will be explained. The construction phase challenges will be next and the requirements for the design review of some bridge components (as the construction of the bridge progressed) will be described in the next following sections. At last, the features of the Design and Construct contracts will be discussed and the learning from this case study will be highlighted.

**Project Background**

The existing Einsleigh River Bridge was located on the Gulf Developmental Road, approximately 35 km west of Mount Surprise (Chainage 56.2km) North of Queensland. It was located on the main inland route from the eastern coast townships to the township of Georgetown and onto Croydon and Normanton. The existing bridge and approaches were constructed in 1965, the river crossing is approximately 600m long comprising of a bridge with causeway approaches, the two lane bridge is approximately 6m wide, 171m long with 16m spans, the existing causeway approaches total approximately 400m long. The existing bridge and causeway was extremely flood prone, with seasonal flooding resulting in bridge deck overtopping and damage to the causeway approaches. The frequency of flooding and regularity of damage caused by even minor flood events has prompted funding requests to allow construction of a new bridge with a deck height of approximately 5m above the level of the existing bridge.

![Fig. 1. Existing Bridge Plan and Side View](image)
**Proposed Bridge Structure**

The proposed bridge was constructed under a “Design and Construct” contract by Davbridge Constructions P/L. Opus International Consultants were the engineering consultants engaged by Davbridge to provide civil and structural design and documentation for the bridge and its approaches.

The minimum bridge level has been defined by the Department of Main Roads to provide a minimum level of flood immunity to the bridge. In addition to the minimum RL, the bridge height was further increased by 50mm in the schematic design stage to allow a waterway area of $2212\text{m}^2$ below the bridge deck. The bridge deck spans were chosen as 12.6m based on the maximum weight girder that could be efficiently transported to the site from the precasting yard. The new bridge consisted of 33 spans, resulting in a bridge length of approximately 416m.

![Fig. 2. Construction of New Bridge Next to Existing Bridge](image)

**Bridge Design Overview**

**Design Load Cases**

The following table indicates the loading assumed in the design of the bridge structure: [2]
### Table I. Design Load Cases for the Einasleigh River Bridge

<table>
<thead>
<tr>
<th>Type of Loading</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Deck Wearing Surface</td>
<td>Based on calculated asphalt thicknesses</td>
</tr>
<tr>
<td>SM1600</td>
<td>Calculated for 2 traffic lanes positioned in the “worst” location on the bridge</td>
</tr>
<tr>
<td>HLP400</td>
<td>Load Positioning +/- 1m from the centreline of the bridge</td>
</tr>
<tr>
<td>Wind Loading</td>
<td>Calculated from AS1170.2, Region A</td>
</tr>
<tr>
<td></td>
<td>$V_{500,50} = 41$ m/s</td>
</tr>
<tr>
<td>Earthquake Loading</td>
<td>Bridge assessed to be BEDC-1, no specific earthquake analysis undertaken for this span length</td>
</tr>
<tr>
<td>Water Loading</td>
<td>$Q_{2000}$ flood at 4.36 m/s and RL352.1m</td>
</tr>
<tr>
<td></td>
<td>Calculated debris load at pier 502kN</td>
</tr>
<tr>
<td>Braking Loading</td>
<td>720kN, single lane stopping</td>
</tr>
<tr>
<td>Thermal Loading</td>
<td>To AS5100.2, $T = 20$ degrees</td>
</tr>
<tr>
<td>Barrier Loading</td>
<td>To AS5100.2, “Regular Performance Level”</td>
</tr>
</tbody>
</table>

### Geotechnical Investigation

A geotechnical investigation has been carried out at the site in February 2010. This report sought to quantify the rock quality generally and provide some conservative design parameters. The initial fieldwork was focussed on the Georgetown abutment where the rock was deeper (test pits had previously allowed visual inspection of the rock at Mt Surprise end of the proposed bridge). Following this initial investigation and after commencement of the design, further boreholes were commissioned to at each pier location to confirm the test pit inspections and depth/quality of rock at each pier. These borehole investigations were ongoing to keep pace with the construction (as the water levels in the river recede in the dry season). Generally, the geotechnical fieldwork determined that high level, very hard rock exists near the surface for a majority of the bridge. Deeper rock overlain by extremely weathered rock was found to exist at the Georgetown end of the bridge.
Substructure

**Piers with High Level Footings**

Given the proximity of the rock to the surface for a majority of the bridge, piers at locations with high level rock have been designed to be supported on pad footings. The pad footings are designed as precast to minimise the volume of site (insitu) concrete. Given the lack of a close supplier of concrete and the subsequent need to cart concrete long distances, reduction of in-situ concrete is considered important to minimise risk and guarantee quality. Following establishment on site, further backhoe test pits were carried out by the contractor at each pier location and it was determined that the high level footing option would be applicable for internal piers due to the actual location of the rock on site.

**Reinforced Blind Concrete**

Following excavation, it was discovered that the rock exists in very hard bands through the proposed excavation. Attempts to provide a level surface were determined not practical due to the difficulty of removing the rock bands. A review of the design allowed this very hard rock to remain as is with a deeper lift of blinding concrete employed to provide a level surface at the top. The blinding was originally detailed as being essentially mass concrete with light mesh
reinforcement in layers merely for crack control of the concrete [1]. In discussions with TMR, an alternative philosophy for reinforcing this blinding was established in which additional reinforcing bar was provided for depths of concrete greater than 400mm (up to 800mm). As an analysis of the concrete structural blinding indicated very low stress levels, the additional reinforcement areas were calculated purely on the AS5100 “minimum” reinforcement provisions for flexural members at the instruction of TMR [3].

Excavation on site also yielded some localised holes of more weathered material that were removed during construction. Some of these holes were determined as being quite deep, the weathered material was removed to solid rock at the base and the holes have been detailed as being filled with mass concrete. Where the hole was around 1m² at the top and enclosed with rock on all sides, it was determined that the confinement would allow mass concrete to be used (no reinforcement). Where the holes were larger and without confinement on all sides, a reinforcement detail was developed that allowed the increased depths.

![Fig. 4. Reinforced Blind Concrete Under Pre-cast Pad Footings](image)

**Precast Reinforced Concrete Pad footing**

Following casting of the pads, the design allowed for passive anchors to be grouted into the SW/FR rock. These anchors have been detailed as being galvanised in accordance with MRTS03 [3]. Per discussions with TMR some PVC conduit will be detailed at the interface between rock and precast to minimise instance of moisture getting to the bar along the interface between materials. The grout specified and required test loading procedures are also in accordance with this specification. Following anchor installation, the precast pads are to be lifted onto the blinding concrete which has been screeded with a thin
layer of proprietary high strength grout prior to placement of pads to ensure a uniform bearing between the two surfaces. The shear loads due to sway frame loading are catered for in a number of redundant ways. Firstly, the compression of the structure on the surfaces will provide for a shear friction capacity. The capacity of shear friction was determined by Clause 8.4 of AS5100.5 with the conservative assumption that no bond exists between grout and precast element (ie relying purely on the compression across the interface). Even with conservative parameters, this by itself is sufficient to transfer out the load [2].

To provide redundancy on this load transfer, and to provide additional positive fixity, a number of shear dowel anchors have been detailed to take the full shear load to the rock below. The analysis of the high level footing piers was carried out in Microstran with all appropriate vertical and lateral loadings applied to the model [4]. The pier was designed as a sway frame with fixity at the column/headstock connection and at the column/pad connection to minimise the moments at these connections. Uplift was calculated on the upstream pier, while the downstream piers were determined to be always in compression. Uplift is proposed to be taken out by grouted reinforcing bar anchors. The length of embedment is calculated from the top of SW/FR rock (bottom of blinding) and subsequently the contractor will be recording the RL of the rock at each anchor location prior to casting of blinding to ensure that the correct bar lengths are scheduled [1]. The capacity of the anchors was determined by calculation of the bond length required, a rock cone failure mechanism (per geotechnical advice), and the structural capacity of the bar. In all cases, the rock cone was the critical mechanisms that determined embedment lengths. This means that the actual bond stress on the anchor is significantly less than the design capacity. The precast pad will have oversize voids cast into it to allow the anchors to pass through the precast pad and into the columns over. The anchors are positioned under the column locations, so the anchor reinforcement can be developed by a full lap cast into the in-situ column.
Precast Reinforced Concrete Headstock

The precast pad footing, in-situ columns and precast headstock have been designed to take the loading (moment, shear, axial) as determined by the frame analysis. The connection between the precast concrete headstock and in-situ column will be via a cast in-situ infill. This infill will be wedge shaped to provide for some bearing on the inclined faces and to minimise the shear forces acting on reinforcement (dowel action). Bursting forces as a result of the infill wedge have been determined and additional reinforcement crossing the tension planes has been provided for these forces. The connection has been detailed with artificial roughness of the face to maximise the bond between infill and precast. The starter bars out of the column have been designed to carry the imposed forces. Where the starter bar is not fully developed due to a shortened embedment length, the proportion of the area of steel developed has been used in the calculation [2].
Fig. 7. Pre-cast Headstock and Void Infill at Column Connection
Following preliminary design, it was determined that there would be no instance where a deep (cast in-situ) pier will be required. We have designed an alternative however to allow flexibility for the contractor on site should this be required at a later stage due to uncovering of latent conditions. The deep footing option shows in-situ cast in place piers utilising driven steel liners. During the construction it was found that the piers number 1 and 8 require deep footings due to their ground conditions having SW/FR rock at very deep level. The typical design details for the deep footings have been revised to suit individual piers no. 1 and 8. Therefore, separate design details were prepared for each of the piers.
Fig. 9. Bored Piers at Piers with Deep Footing
The analysis was in Microstran and also reflected a sway frame analysis [4]. The frame was designed with pin bases at the bottom of the bored piers. The bored piers connected into a reinforced (in-situ) concrete ground beam. The two bored piers support three columns over; hence the ground beam also acts to transfer the column load to the bored pier locations.

**Abutments with Deep (Cast-in-place Pile) Footings**

The drawings indicate cast in place piles for the abutments. These were constructed using liners driven through the compacted embankment fill. A Microstran frame analysis has been carried out assuming fixity at the base of the piles and ignoring any lateral support from the embankment material (scour) and a fixed head (sway) frame [4].

As with the deep footings, if a socket is not achievable in the rock, the toe of the pile has been detailed with passive dowels for shear connection.

*Fig. 10. Bored Piers at Abutments*
Superstructure

Deck Units and Kerb Units

The deck and kerb units have been analysed using a Microstran grillage analysis with moving loads to determine the critical loaded girders [4]. Following analysis, the girders have been analysed using RAPT for prestressed concrete design. The RAPT design was further checked via a spreadsheet stress and ultimate capacity analysis [5].

The analysis took into account that the kerb unit was significantly stiffer than the adjacent deck units (due to increased depth). This has resulted in the kerb unit relieving some of the stress in the adjacent outside deck units. The two live load cases (SM1600 and HLP400) were analysed and the critical girder determined [2].

The kerb unit was designed separately for its own forces. A critical aspect of the kerb unit design related to the design for transferring out the torsion from the regular barrier impact forces. The design adopts the TMR standard steel bridge barrier, and per discussions with TMR we have allowed for a torsional force to be applied to the edge girder equal to the yield moment capacity of the barrier post. The design reflects shear ligatures in the kerb unit to carry these forces back to the laterally stressing bar locations. Additional reinforcement has been provided in the kerb units as a response to the longitudinal stresses per the AS5100.5 recommendations for design for torsion [2]. The precast girders are laterally stressed with the kerb units per the standard TMR design [3].

Fig. 11. Pre-cast Deck/Kerb Units Installation
Features of Design & Construct Contract

There are a number of observations which might be made in relation to design and construct contracts as presented below.

Importance of Design Brief

The Design Brief is a document which is attached to the Design & Construct Contract. That document describes the works which are to be constructed for the Contract Sum and includes the following:

1. Schematic drawings of the proposal;
2. General specifications of the proposal and performance criteria for the works when complete;
3. Site information;
4. Any other technical details which impinge on the Works which are to be constructed.

The preparation of the Design Brief is a matter for the Principal. Usually that function will be performed by the Principal's design consultants. The Design Brief is not intended to be a detailed design, merely that it is sufficiently detailed to express exactly what it is that is to be designed and constructed by the Design & Construct Contractor. The Design & Construct Contract obliges the Design & Construct Contractor to produce a detailed design, to comply with the requirements expressed in the Design Brief, and to obtain the approval of the Principal (usually the Principal's design consultants who prepared the Design Brief) prior to commencing construction. Claims usually arise, at this point, between the Principal (on the basis that the detailed design has produced is low quality, or does not adequately perform the function which is described in the design brief) and the Contractor. It is critical, therefore, for the Design Brief to be adequate in describing the works which are to be constructed and the functions which they are to perform.

Buildability

The principal advantage of a design and construct contract is that it allows the construction contractor to bring his construction expertise into the design process. There is a view that the ability of the construction contractor to design the works with the convenience of construction in mind will result in cost savings to the
Principal at the time of tender. The design and construction contractor is able to incorporate certain design criteria which may suit the contractor for ease of construction. Accordingly, the tender price is likely to be lower (taking into account the cost of the actual design work) than where a Construction Contractor was pricing works which had been designed by others, with no regard to the "buildability" of that design. Further, the capacity of any contractor to incorporate the "buildability" into a particular project design is directly related to his previous experience in design and construction. The incorporation of construction expertise in the design process is certain to result in substantially more efficient designs and lower tender prices.

**Single Point of Responsibility**

There are a number of potential situations in traditional style contracts where the boundaries of the responsibility of the designer for design and the construction contractor for construction may become unclear. There is potential for dispute where the works as constructed fail to perform in accordance with the specifications (for example, leaking, cracking, discolouration ...). In such instances, the construction contractor might claim that the problems are a design issue, whereas the designer might assert that the design was adequate but the works as constructed did not comply with that design. Where the contractor has responsibility for both the design and construction, this problem does not arise.

There are several such potential areas of overlapping responsibility. For example:

1. Claims sometimes arise in traditional contracts (where the detailed design has been performed by the principal prior to entering into the contract) where the contractor is asserting that the design cannot (or cannot conveniently) be constructed;
2. Where the works, as constructed, do not perform the required function in accordance with the specifications, and/or are defective, a difficulty sometime arises where the contractor is asserting that the problem is a design fault, and the designer is asserting that the problem is a construction fault;
3. Claims sometimes arise where the construction contractor is delayed by the designer during the construction phase (for example, in waiting for asserted errors or ambiguities in the design documents to be resolved).

In each of those instances, the principal would be faced with the designer and the construction contractor blaming each other and denying liability to the principal. Where the Design & Construct contractor has responsibility to produce the detailed design, this type of claim will not arise.
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Perceived fast tracking

There is a view that a Design & Construct contract increases the possibility for “fast tracking” of the project. Some minor improvements in the programming of capital works can often be achieved through the Design & Construct model. The pre-tender phase is likely to be shorter than for a traditional contract (because it is only necessary to prepare the Design Brief, rather than the detailed design) prior to inviting tenders. The detailed design work is able to be performed after execution of the Design & Construct Contract, and during the early stages of construction, in a staged manner.

Potential for Dispute

The unique area for dispute arising in design & construct contracts, rather than traditional contracts, arises at the time of review of the contractor's detailed design. The contractor must design the works in accordance with the Design Brief. However, the Design Brief will be descriptive rather than detailed and will rely on defining function and performance criteria, rather than specific design elements. The contractor will naturally be inclined to use lesser quality materials to reduce cost. The principal, on the other hand, would usually have a higher impression of the degree of quality which was intended within the Design Brief. This is due to the fact that the required materials and workmanship which is to be performed under the contract, is not adequately described.

Potential Design Conflict

A potential conflict for the contractor may arise in designing the works under a Design & Construct contract. The contractor, having contracted to construct the works for the contract sum will be required to make a number of design decisions. Accordingly, the contractor in performing his design role will have a conflict between the proper performance of that design role and the desire to keep costs to a minimum. The contractor as the designer, would also wish the materials and workmanship to result in a constructed product which performs adequately (at least in accordance with the Design Brief).

In designing the works, a contractor might be inclined to use lower quality materials (where they have not been specified in the Design Brief) irrespective of the design life of those materials. The Design & Construct contractor may also
conclude that his contractual obligations cease at the end of the Defects Liability Period. This is not strictly correct, however problems of proof may make this practically so and, therefore, there is no reason for the Design & Construct contractor to prefer more expensive materials to less expensive materials, provided that the less expensive materials would last at least to the end of that Defects Liability Period. The principal, on the other hand, would prefer the more expensive materials in order to reduce long term maintenance costs. This issue would usually arise at the stage of approval by the principal and will turn on what has or has not been specified in the Design Brief. This is an example of the type of detail which should be included in the Design Brief.

Choice/Quality of Designer

The design & construct tenderer, when bidding on the tender documents, will usually be required to disclose the identity of the detail designer. The principal will usually wish to have some control over the choice of designer. The principal may have a particular preference or merely interested to have a suitably competent designer. On complex projects, the principal may require the engagement by the contractor of a suitable firm of professional design consultants. In this manner, the principal will have remedies against the contractor in contract and against the professional consultants in negligence should the detailed design ultimately prove to be inadequate. The Principal will also wish to ensure that the particular design consultants have adequate professional indemnity insurance. The perceived disadvantage as to choice of designer, when weighed against issues of "buildability" and single point of design responsibility, may be misleading.

Contract Administration not by Original Designer

There is a perceived disadvantage in having the administration of the construction contract performed by a person other than the original designer. It is correct that the original design philosophy is likely to be more adequately addressed by the original designer than by a professional who did not perform the ultimate design. However, this disadvantage could be sometimes deceptive and misleading. The likelihood is that, subject to the choice of a suitable person for the role, any professional contract administrator would have regard to the design philosophy in superintending the construction of the works.
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Risk Allocation under the Design & Construct Contract

The allocation of risk under a Design & Construct contract is slightly more complex than under a traditional contract. Under a traditional contract, the adequacy of the design with all of the consequences which flow from inadequate design in respect of both the works and delay or additional costs caused to the contractor, rests with the principal. The principal may or may not have adequate remedies against the original designer pursuant to their separate professional engagement agreement. Unlike the traditional contracts, the responsibility for detailed design rests with the contractor. There are a number of risk areas for the contractor in this role:

1. Compliance with the Design Brief;
2. Adequacy of the design generally;
3. Design approval by the relevant building authorities.

Lessons Learnt in this Study

The major achievement in this project (under the D&C contract) was a significant saving in cost the construction as the result of a close relationship with the experienced contractor who could direct the designer to a more simplified and practical design detail with ease of construction.

An effective collaboration between the design engineer (with design experience) and the contractor (with construction experience) during the design stage resulted in a very cost effective design for the precast deck units. The optimisation analysis on the design of the deck units revealed that the governing parameter is the length of the deck units where the section size and the associated weight of the member could affect the transport conditions and the associated costs. The optimum length for the pre-cast deck units was found to be 12.6m long where the total weight of each unit was 8.2 ton. It allowed to have 3 units being transported in a single trailer with minimum overhang from the back of trailer and no need for the traffic escort.

The other learning from this project was how the design-related construction issues were tackled during the construction. The close monitoring of the
construction progress and reviewing of the design at different stages of the works ensured that the construction of the bridge was in accordance with design requirements. For instance, the deep footing foundation design for the piers was not initially considered due to the level of the surface rock layers. However, during excavation of footings, it was found that two piers require deep footing foundation. Therefore, the new design for those piers was developed at the time of construction with no delay in the progress of the work.

There were a couple of instances where a conflict arose in the construction stage. Due to ambiguity in the design brief, the infill product specified in the structural drawings to fill the hold down bolt holes in the headstock/deck units connection was not exactly nominating an arbitrary product. An arbitrary grout infill product was specified in order to comply with the TMR requirements. It resulted in additional expenses which could not be claimed from the principle. The contractor blamed the designer why this issue was not resolved during the design stage and as the results no payment was paid to the designer for re-designing of the element using the nominated product.

Summary

In summary, a case study was undertaken on a new replacement bridge by Opus International Consultants under a Design and Construction contract. The advantages of the Design and Construct contract as one of the most common contractual methods of road infrastructure construction have been discussed. It was found that the principal advantage of this type of contract is that it allows the contractor to bring his construction expertise to the design process. This will result in a significant cost saving to the client.

A case study was undertaken on the process of design of the Einasleigh River Bridge where all the D&C contract challenges were discussed as faced within the design and construction phases. From the tender stage it was found that the deck unit length is the governing parameter in the overall cost of the project. Therefore, a two-lane replacement bridge was designed based on the 12.6m long span with an optimum girder length and size to minimise the cost of materials. The proposed bridge had an overall length of 416m, 33 spans and 5m above the existing bridge level. The design also provided an efficient transportation system where the 561 girders were transported 1800km from Brisbane to the site. An innovative design approach was also adopted to overcome the overturning forces and stability issues of the bridge. All the design challenges, issues arose during construction and the benefits of having a Design and Construct contract as experienced in this project were discussed. It also highlighted that the innovative design approach adopted in this project resulted in a cost saving of about 5million dollar for the client.
Acknowledgement

Opus International Consultants were commissioned under a “Design and Construct” contract by Davbridge Constructions (the construction contractor) to provide civil and structural design and documentation of the Einasleigh River Bridge for the Etheridge Shire Council. The Department of Transport and Main Roads was the government authority provided the required approvals for both design and construction stages.

This project and the following studies could not be accomplished without the full cooperation and assistance provided by TMR and the Etheridge Shire Council. It is also greatly acknowledged the Davbridge Constructions that provided Opus with this design opportunity and bringing the extensive construction experience to the design of this bridge.

References

[5] RAPT Reinforced And Post-Tensioned V6.2.2.2, Structural analysis and design Package for Reinforced Concrete Structures (2010)