



ACCELERATED BRIDGE CONSTRUCTION IN NEW ZEALAND THE DESIGN PROCEDURE

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SUMMARY

Adopting an Accelerated Bridge Construction design philosophy can provide savings in both construction costs and time combined with wider economic benefits. This philosophy was critical to the successful construction of recent bridge replacement projects in New Zealand, including replacing a bridge over live rail within a period of five weeks. This paper discusses the design procedure behind the Accelerated Bridge Construction philosophy and how it has been successfully implemented in bridge replacements for Mount Wellington Highway, Morrin Road and Jutland Road in Auckland.

INTRODUCTION

Accelerated Bridge Construction (ABC) is a method of delivering bridge construction or replacement projects within significant time constraints and provides the following project benefits:

- Improved material quality
- Improved whole of life costs
- Reduces road and rail traffic impacts
- Reduced on-site construction time
- Reduces labour intensive activities

This method usually requires greater efforts in the design process and the highest level of construction management and planning, in comparison to standard bridge construction. Commitment to adopting Accelerated Bridge Construction is required by the client from the onset of the project, including engaging in the design process and awarding the construction with an emphasis on the ability of the construction personnel. Extensive construction planning and co-ordination with all stakeholders are required throughout the design process to ensure all potential issues are recognised and resolved prior to construction. This meticulous procedure will incur a higher design cost, but should result in a lower overall project cost by minimising the construction period and adopting efficient construction techniques.

Mount Wellington Highway, Morrin Road and Jutland Road are three recent bridge replacement projects that successfully adopted the Accelerated Bridge Construction process. All three structures are road-over-rail bridges with spans between 16 to 20 metres. The bridges were replaced to gain additional vertical rail clearance as part of Kiwirail's Auckland Electrification Project. They all consisted of an existing concrete structure that was demolished, and replaced by new substructures and a prestressed concrete superstructure with shallower structural depth.

This paper focuses on the three main steps to design for Accelerated Bridge Construction, and highlights project specific features that provided construction and wider economic benefits.

ASSESSMENT OF PROJECT CONSTRAINTS

Project constraints provide the framework in which a solution can be developed to satisfy the project objectives. A clear understanding of the project constraints is fundamental to the ABC design procedure, the three main constraint categories are:

- Physical site constraints
- Stakeholder requirements
- Design and construction team ability.

The constraints should be determined in the early stages of optioneering, ensuring that all significant issues and risks are identified and resolved efficiently in terms of construction programme and costs. Well-defined project constraints from the onset will also assist the optioneering process, reducing significant rework later in the design process.

Physical Site Constraints

Physical site constraints include the interface with property boundaries, clearance requirements, site access constraints, geometric alignments and other existing features such as service providers.

Mount Wellington Highway Bridge was extensively used by five service providers to facilitate their services across the rail corridor. Property boundaries were less than a metre away from both sides of the bridge and a 40-metre long timber retaining wall adjacent to the bridge had to remain unaffected by the project works. A proactive approach was adopted by the designers during the design process to identify and resolve these issues with all parties involved.

Stakeholder Requirements

Stakeholder requirements form the objectives of the project. The key stakeholders of the bridge replacement projects discussed in this paper were KiwiRail and Auckland Transport. Minimising the disruption to all modes of transport was a key requirement from both parties.

Train movements on the North Island Main Trunk (NIMT) in Auckland are at 30-40 minute intervals between 11pm and 5am and at 10-15 minute intervals at all other times. Therefore, design solutions were developed which allowed the rail network to be operational during construction, with some of the demolition and piling works completed during Kiwirail's Christmas Block-of-Lines (BOL). Thorough construction planning is crucial during the design process to ensure there were no delays in reopening the railway tracks.

For example, Mt Wellington Highway Bridge consisted of 28 simply supported slender prestressed deck beams. The ABC deck solution allowed the deck to be constructed with minimal BOL requirements, with all beams being installed between trains in a combined duration of eight hours.

KiwiRail required the bridges to be future-proofed for a future third main. Developing a solution which achieved the minimum required vertical and lateral rail clearances on Mt Wellington Highway Bridge was complex. The rail tracks are curved and the abutments are on a high skew of 26.3°. The solution was developed by modelling a moving clearance envelope along the tracks in 3D, and designing the bridge structure around the envelope whilst minimising road pavement reconstruction.

Providing a suitable temporary traffic management solution is paramount to giving the TLA confidence to close the road for the duration of the works. Implementing ABC principles successfully can dramatically reduce the overall disruption to public, particularly for bridges on major arterial roads.



Fig 1 Support structure for required traffic lane width

For Mt Wellington Highway Bridge, a major arterial road serving State Highway 1, Auckland Transport had a requirement that at least three lanes remain open at all times. Therefore, the replacement of Mount Wellington Highway Bridge was constructed in two stages. Temporary support brackets were installed and existing bridge beams were retained during Stage One in order to provide sufficient width for the three traffic lanes requirement (refer **Fig. 1**).

Design and Construction Team Capability

The capability of both the design and construction team has a significant impact on how effectively ABC principles can be implemented to achieve the project objectives. It is critical to have senior engineers, with knowledge of construction, who can guide the solutions during the concept and preliminary design to ensure constructability. An innate understanding of construction tolerances is a major factor in being able to simplify the construction sequence and minimise the construction period.

As with any construction project, unforeseen issues may arise during construction. With ABC, the agility of the contractor as well as the ability of the site engineers from the design team is very important as issues need to be resolved promptly. In addition, the designer must be intimately involved with construction proceedings, providing assistance and adding value where possible. All parties involved in the project, the designer, constructor, client and keys stakeholders must adopt a proactive and collaborative work ethos to work on best for project solutions.

BRIDGE CONCEPTS AND APPRAISAL OF DESIGN OPTIONS

The client's objectives and project constraints form the framework in which the concepts are developed. Concepts explore span, abutment and pier arrangements, challenge constraints and try varying structural forms with the purpose of developing solutions that are project specific. The complexities of a rapid bridge replacement in a constrained live rail environment almost exclusively demand project specific design solutions.

In the case of Morrin Road Bridge, a major stakeholder requirement was to minimise the duration of road closure. The available detour routes were significant and had a significant effect on the local businesses. As the bridge is situated on the edge of a basalt flow from nearby Mount Wellington, a dormant volcano, a reduced construction period was achieved by minimising excavation of the basalt flow (which had an Unconfined Compression Strength of greater than 20MPa).

The concept to minimise rock breaking was to create a fully integral bank seat and post-tensioning the concrete foundation pad to the basalt flow (refer **Fig. 2**). To minimise the associated road works while achieving the maximum clearance, haunched integral bridge beams (refer **Fig. 2**) were developed to minimise the structural depth and taking advantage of the rail clearance envelope.

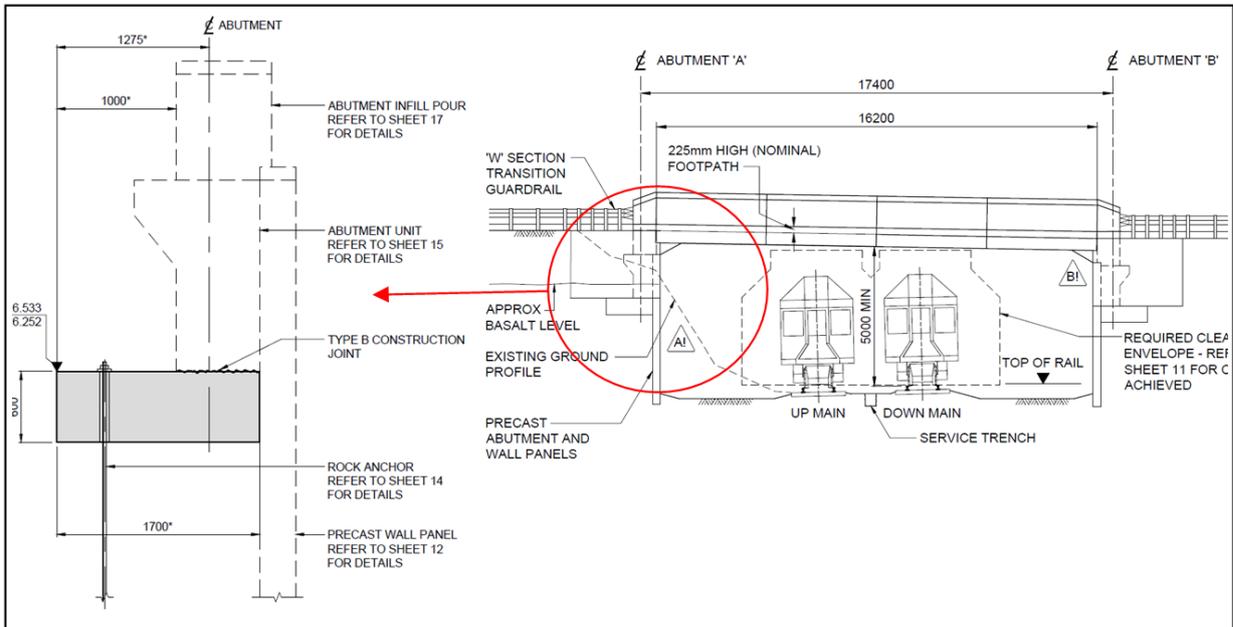


Fig 2 - Morrin Road bank seat and haunched integral beam innovation



Fig 3: Precast abutment & retaining wall units.

Speed of construction was critical for the success of Mt Wellington Highway Bridge. Given that the bridge consisted of 32m width of bridge deck and over 70m of new retaining wall, a modular and repetitive solution was developed which could be implemented for both the abutments and the retaining walls (refer **Fig. 3**).

To ensure the optimum solution is developed, an inter-disciplinary-check (IDC) is conducted, which brings together all design disciplines, clients, and where required, key stakeholders, to discuss the options developed to date using options drawings (refer **Fig 4**).

Non-price and price options comparison matrices are used to quickly assess the benefits of each option, test the constraints and objectives and identify new constraints and objectives.

Using the price and non-price matrices (refer **Fig 5** and **6**) the preferred option for Jutland Rd would have been Option 7, however, it was determined that removing a grade separated crossing was not an acceptable option to Auckland Transport and a new constraint was imposed on the project.

The outcome of the IDC will be the nomination of preferred option or further options for development and review. Upon nomination of the preferred option further review of the constructability is conducted and a baseline construction programme developed against which future decisions and design development will be assessed, at this point and subject to the refined analysis, the nominated option is 'locked-in' as the preferred option. Once the preferred option has been selected a design statement can then be prepared for the selected bridge concept during the preliminary design and finally the detailed design.

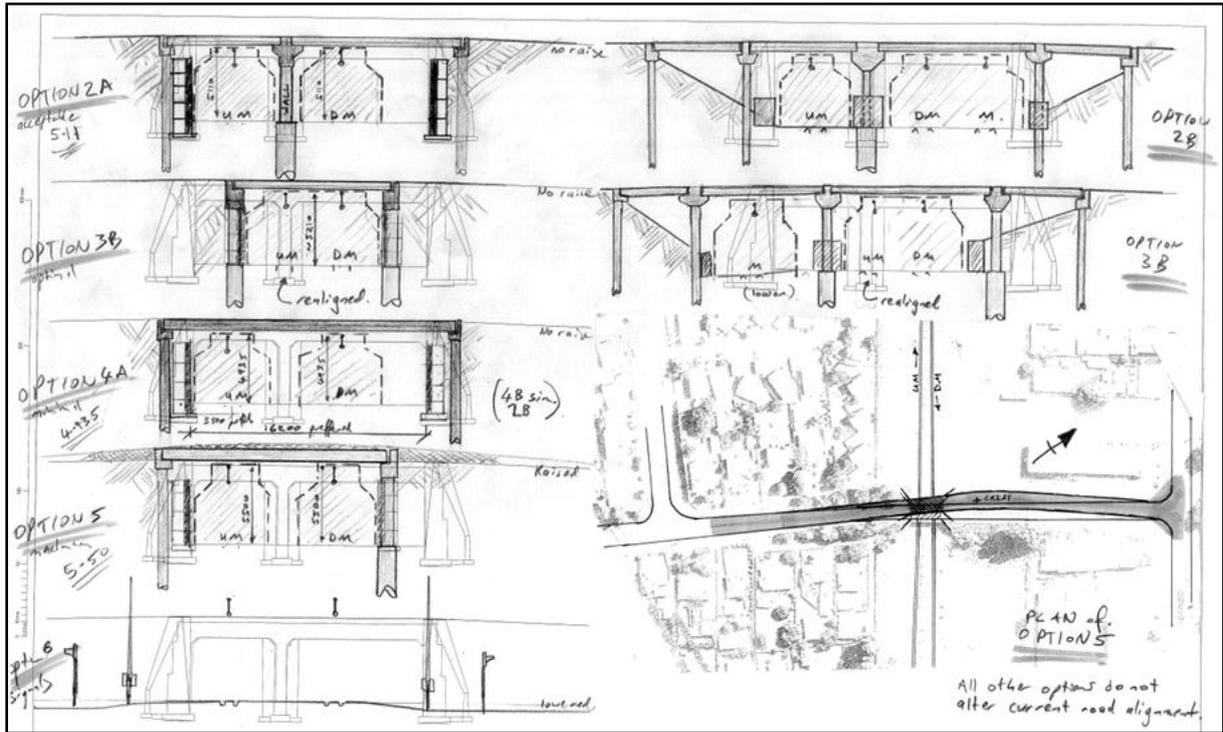
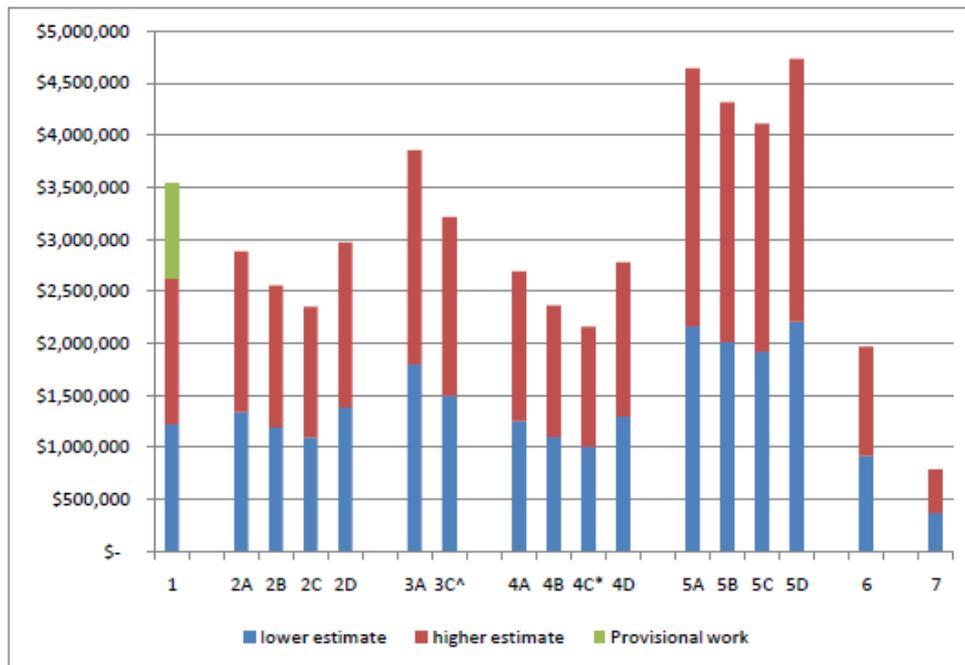


Fig 4: Design options for Jutland Road Bridge.



^ Options 3B and 3D are not physically possible in a logical construction sequence
 * 4C is the preferred option

Fig 5 – Options Comparison Matrix (Price) for Jutland

Option	Description	Like-for-like Replacement	Achieves 5500mm vertical clearance	Meets preferred Type 'G' envelope	Meets minimum Type 'G' envelope	Constructible before 2010 Christmas BOL	Constructible within 5 week road closure	Flexible for future track realignment
1	Lower tracks							
2	Replace two spans	✓			✓		✓	✓
3	Replace with short single span	✓		✓	✓		✓	✓(3A)
4*	Replace with long single span	✓			✓	✓	✓	✓
5	Realign road for full clearance		✓	✓	✓			✓
6	Replace with level crossing		✓	✓	✓		✓	✓
7	Remove intersection		✓	✓	✓		✓	✓

* 4C is the preferred option

Fig 6 – Options Comparison Matrix (Non-Price) for Jutland

DESIGN FOR CONSTRUCTION

The designer must maintain focus on the construction programme, throughout all aspects of the design, to achieve an accelerated construction outcome. To ensure that the design and construction intent is transferred to the constructor, a detailed construction sequence that visualises the anticipated construction programme is developed to aid knowledge transfer between designer and constructor.

Services

Early identification and mitigation of services is a priority to the successful delivery of an ABC replacement bridge. Extensive consultation with the local service providers and site investigation is undertaken to provide a 'no surprises' environment on site. The preferred option for the services is for them to be taken out of service for the duration of the construction, but in some circumstances services are required to be kept live in which case an enabling package is let to divert the services.

Prefabricated Bridge Elements and Systems

A key facet of ABC is Pre-fabricated Bridge Elements and Systems (PBES). The aim of PBES is to maximise the use of pre-fabricated elements by designing structural connections capable of transferring the required actions between elements whilst maintaining maximum construction tolerance. Figure 7 illustrates a high level construction programme, including pre-cast elements for Jutland Road Bridge, which was replaced in a five week period.

The time savings achieved by Accelerated Bridge Construction and PBES is demonstrated in Figure 7, where the construction length of the precast elements is given adjacent to the installation to indicate the programme savings given for pre-cast construction against cast in-situ construction. In traditional construction, the pier caps, walls and barriers would be cast in-situ which would have increased the construction programme by approximately five weeks.

The principles of ABC are to remove or alleviate any obstacles that prevent rapid construction. Given the significance of Mt Wellington Highway and the implications on the local road Network and adjacent SH1, the project team elected against a full road closure in lieu of a stage replacement approach. Stage One of the project was completed in five weeks with a 3 week block of line, with Stage Two, which included significant widening, retaining walls, water main and associated road works completed in a further ten weeks with only a three day block of line.

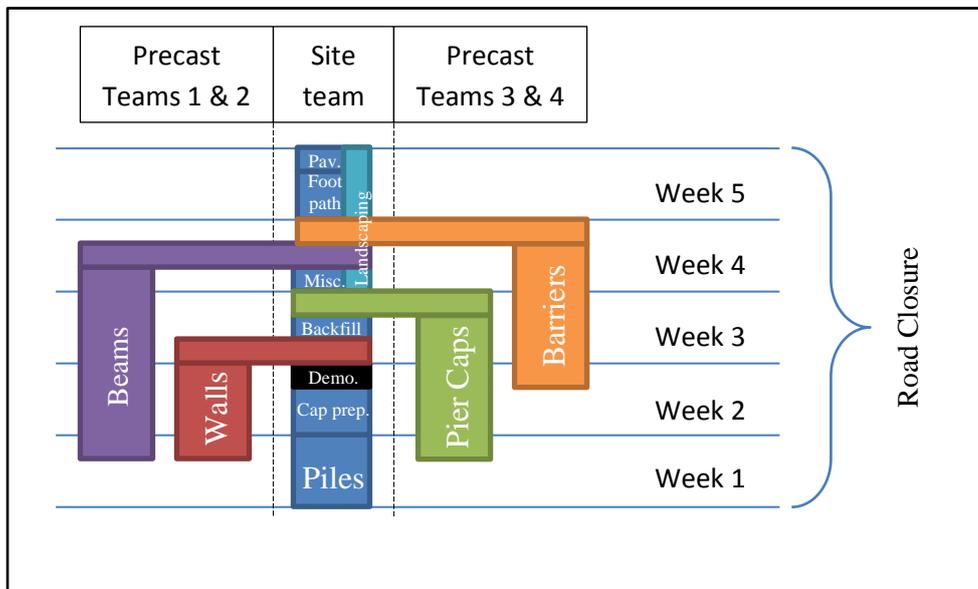


Fig 7 - Indicative Jutland Road Bridge replacement programme

In addition to implementing ABC principles throughout the design stage, successful construction of Mt Wellington Highway Bridge was possible as a result of careful consideration of each stage of construction. In conjunction with traffic flow requirements the temporary works required were detailed and designed into the permanent works where possible.

The method of structural assembly can be designed and communicated through a series of construction sequence drawings. By developing 3D models depicting the construction sequence (refer **Fig 8**), each construction activity could be identified and accounted for in the construction programme and aided the knowledge transfer between designer and contractor.

Innovative Detailing with Construction in Mind

The ABC process results in maximising prefabricated concrete and steel components. Developing innovative methods of connecting these components whilst minimising temporary works is necessary to realise the programme and cost savings intended. For example, significant programme reduction can be achieved by pre-casting the abutment/pier cap. This form of construction was utilised for the Jutland Road Bridge replacement. The system developed to connect the pile to the pile cap and provide a full moment connection was a large post-tensioned bar (refer **Fig. 9**).

For Mt Wellington Highway a piled bridge solution was not appropriate for the geological conditions. The solution developed for the bridge abutments consists of a cast in-situ pad foundation and a series of precast voided box units to build up the abutment. Pre-fabricated steel cages were placed through the voids lapping onto the starter bars from the footing (refer **Fig. 10**).

The precast concrete units and prefabricated cages were easily hauled and delivered to site, with minimal disruption to all modes of transport. To reduce costs the voided abutment units were adapted from standard moulds, with minor alterations to increase construction tolerances and increase productivity.



Fig 8 - 3D construction sequence model of Mt Wellington Highway Bridge

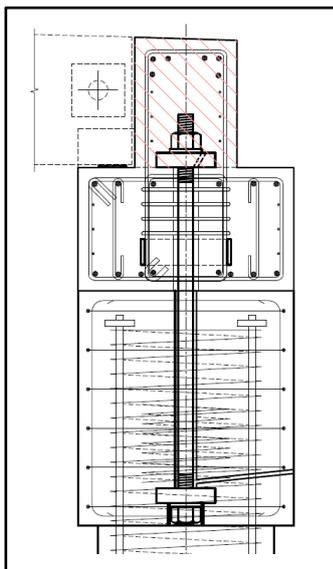


Fig 9: Abutment to pile connection

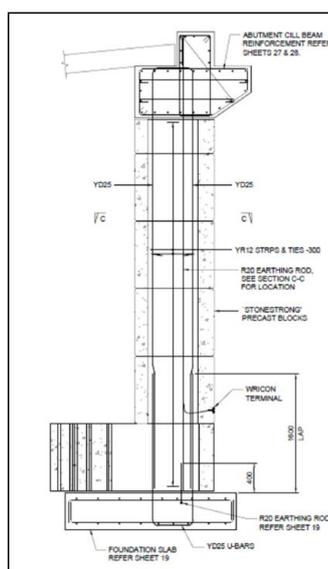


Fig 10: Mt Wellington Highway Bridge abutments



Construction tolerance built into the design is an important aspect of ABC. Beam to abutment connections for integral bridges are notoriously time consuming and simplification of this detail was paramount to the success of Morrin Road Bridge. To provide greater construction tolerance, the abutments were designed to allow the beams to be placed prior to the installation of abutment reinforcing. The YD32 abutment starter bars could be placed after landing the beams, with the longitudinal bars threaded through the cage (refer **Fig. 11**).

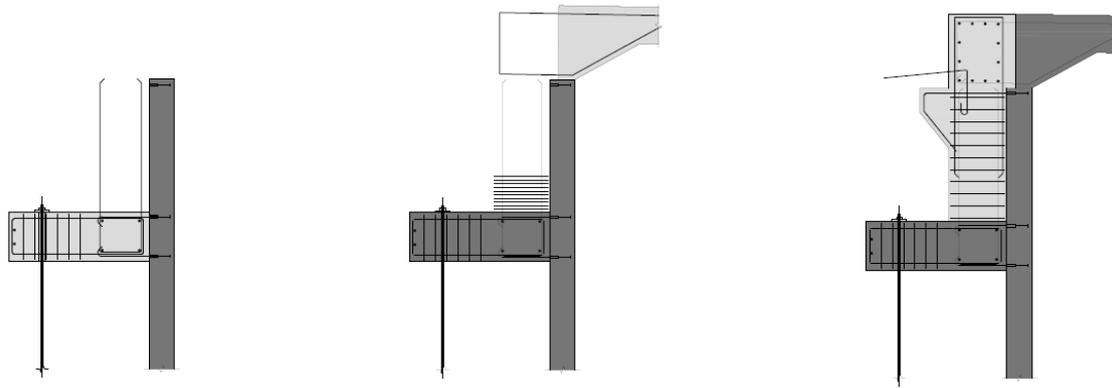


Fig. 11 - Construction sequence of the fully integral abutment connection for Morrin Road

Detailed Construction Documentation

The ABC process requires the designer to deliver a design with a higher level of detail within the construction documentation. In order to minimise the time to procure pre-cast elements and to avoid confusion and the need to issue Requests for Information (RFI's), project or tolerance critical elements are detailed to a higher level of accuracy. Clear and concise set-out information is provided to the constructor in real world co-ordinates for each individual element, this removes the potential for compound errors that erode the construction tolerances provided in the connections for the precast elements.

For example, set-out information for the Morrin Road Bridge precast panels are provided at each corner, with reduced levels for the contractor, along with a construction tolerance of 10mm between individual panels (refer **Fig. 12**).

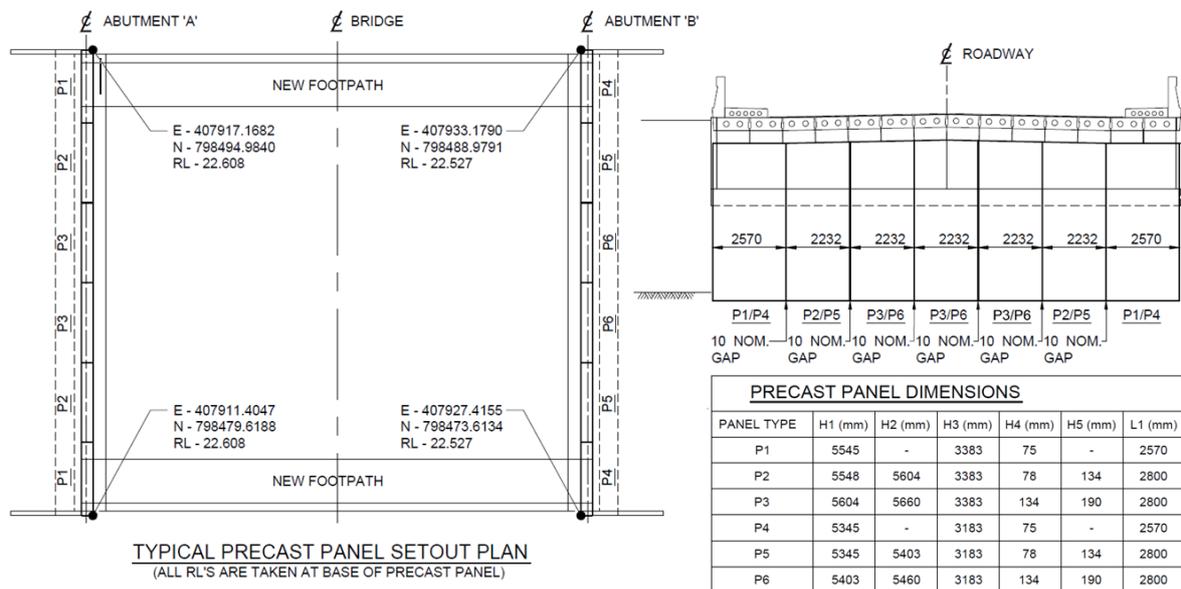


Fig. 12 - Morrin Road Bridge Precast Panel information

CONCLUSION

Accelerated Bridge Construction provides the following project benefits:

- Improved material quality
- Improved whole of life costs
- Reduces road and rail traffic impacts
- Reduced on-site construction time
- Reduces labour intensive activities

A clear understanding of the project constraints is fundamental to design for Accelerated Bridge Construction. Once the constraints are established, design concepts are derived to satisfy the constraints. Development of innovative design solutions which are project specific is an essential task in the process of determining the most effective ABC solution. Appraisal of the solutions during the Inter-Discipline Check process is vital to determining the preferred option.

After establishing the design concept, the final step of the process is to develop a detailed design solution which addresses constructability. Designing for the intended construction sequence, detailing for effective construction using innovative techniques and developing construction drawings with detailed information on construction-related aspects are important requirements of the final step.

Mt Wellington Highway, Morrin Road and Jutland Road bridge replacement projects have been prime examples of the success of implementing the ABC design procedure in New Zealand, and should be used as a benchmark for rapid bridge replacement projects in the future.

ACKNOWLEDGEMENTS

I would like to acknowledge the contributions of the wider project team that included KiwiRail, Auckland Transport, Coffey Projects and Barker and Associates. The efforts of the constructors, Fulton Hogan, who built Jutland Road and Mt Wellington Highway and Downers for Morrin Road, are also acknowledged. Finally I would like to make special mention of the Opus design team that worked on the project.