International Journal of Bridge Engineering (IJBE), Vol. 5, No. 3, (2017), pp. 123-131

INTEGRAL-ABUTMENT BRIDGE INNOVATION AND QUALITY CONTROL - AUSTRALIAN CASE STUDY

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ABSTRACT: The conventional bridge design consists of some type of superstructure resting on an abutment at each end. There may also be one or more intermediate piers as middle supports. This will heavily rely on the expansion joint/bearing for abutments movement, and joint/bearing can be a significant post-construction maintenance issue and increased cost during the life circle of a bridge. Therefore, a new concept was developed to physically and structurally connect the superstructure and abutments to create what is referred to as an integral-abutment bridge (IAB). With this solution, the highly maintenance and costly expansion joint/bearing is eliminated. However, within the construction period, quality control to ensure the end product compliance with standard and design is challenging especially unforeseen river condition will always drive the construction team toward unfavorable outcome and rectification/innovated solutions in this paper provide a case study in Australia for interested researcher and engineer as reference.

KEYWORDS: Integral bridge; Quality control; Innovated solution

1 INTRODUCTION

Integral bridges (IB) are defined as a structure where the superstructure (mainly bridge beams and deck) is directly connected to the substructure (abutment and pier). During thermal expansion or contraction, the superstructure and substructure move together into and away from the backfill. There are no bearings or expansion joints [1]. In Australia, same as other notions in the world, many old highway bridge designs used complicated movement joints and sliding bearings to accommodate thermal effects and horizontal displacements. Unfortunately many of these jointed bridges are exhibiting deterioration of beam ends, pedestals, and piers. The rehabilitation costs for damaged bridge joints and substructures run into millions of dollars annually in US [2].

As a result, integral bridge construction is widely employed and developed in many countries. Especially, numerous integral bridges have been constructed and maintained for decades in USA, the UK, and Canada [3]. Although integral bridges in Australia are not popular compared with the UK and North America, they are increasingly employed in freeway and highway bridges recently. The main challenges related to this type of structures are dealing with soil-structure interaction of the abutment walls, the supporting piles [4], limitation of maximum length and skew angle of the bridge abutment, lack of knowledge and no general codes [5]. This paper indicates the practice of an Australian case – Halletts Way Bridge in quality controls and innovations respectively.

2 BACKGROUND

Halletts Way southern extension project, one of the largest project in Moorabool Shire Council, locating at south-western of Melbourne Victoria, Australia, was commenced in 2016. The plan and elevation views of the bridge are shown in Fig. 1 and 2 below.

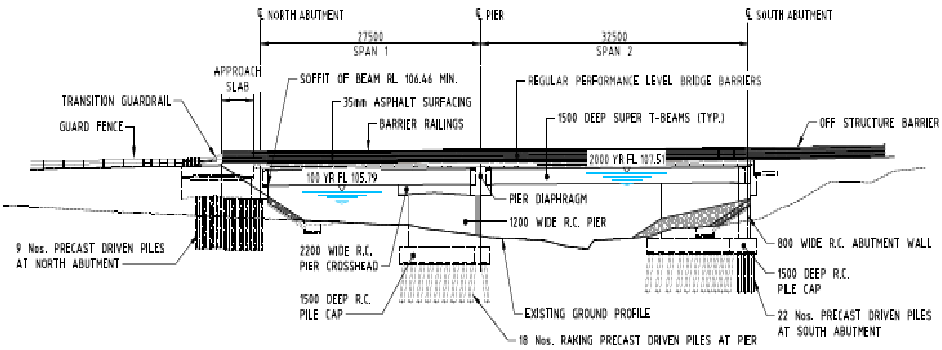

Figure 1. Halletts Way Bridge elevation view

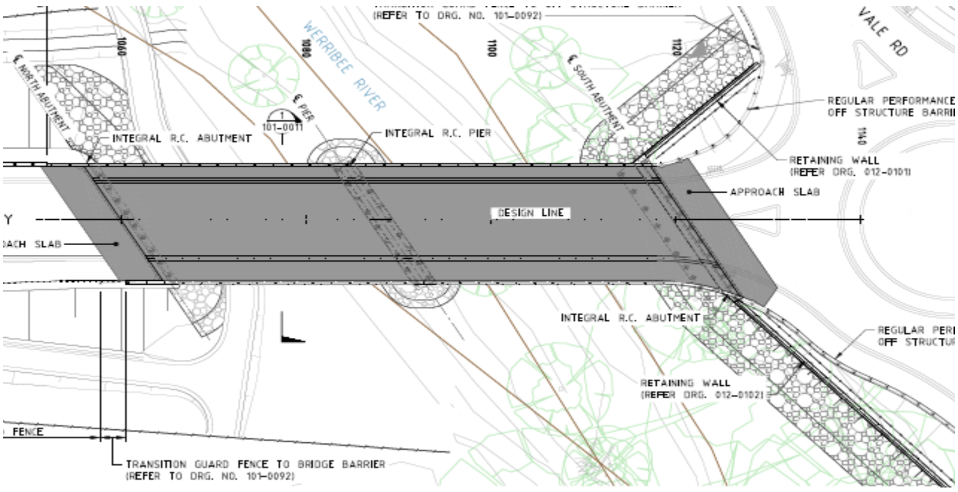

Figure 2. Halletts Way plan view

This project involves the construction of a 1.36km road extension and bridge as part of the establishment of the western link road for Bacchus Marsh, catering for the rapidly growing community. The bridge has two spans, 27.5m and 32.5m with 14.2m wide.

Traffic load allowed for ultimate 4 design lanes (SM1600); the bridge subjected to earthquake acceleration coefficient a=0.095, and flood loading for 2000 year flood flow velocity V=1.33m/s. estimated scour depth for 2000 year flood at north abutment is 3m, pier is 7.5m and south abutment is 2m.

3 CONSTRCUTION OF HALLETTS WAY BRIDGE

3.1 Geotechnical Investigation

Halletts Way Bridge is founded across Werribee River at Bacchus Marsh, Victoria. Within the Werribee River Alluvium (Flood plain) area, it contains approximate 6m silt/clay/gravel, then changes to clayey sand/sandy clay down to 15m depth, with boulder presented, and water appearance at 1.5m below ground level.

3.2 Construction Sequence

The piling works were first driven to their foundation level and trimmed off at the pile cap level; then pile cap, abutment and central pier were established to the level of the underside of the abutment and central pier crosshead. Rock beaching on the face of each abutment slope and central pier protection batter were placed prior to beams installation.

The bridge superstructure was then constructed above construction joints level. Falsework around the bridge beams were erected to complete concrete bridge desk sections, and casting the south, central pier, north diaphragms in sequence.to form continuous superstructure.

The final construction stage involved the approach slabs, wing walls, approach embankments, pavement completion along with bridge barriers and railings.

3.3 Piling Foundation

Northern bridge site contain soils with boulder or prone to liquefaction. According to previous literature, this requires the use of open-ended pipe piles, which tend to be much stiffer than steel H-piles [6]. The project team has adopted a foundation details as Fig. 3.

These piles with pile joints at approximately 9m below so no bending moment will be transferred along the abutment stem. Abutment piles need to have sufficient vertical capacity, but low stiffness to minimize the flexural effects of thermal and other movement of the bridges.

The detailing to achieve flexural continuity at the abutment/superstructure junction simply relies on the top section of piles, pile caps, then abutment and

diaphragm; so these locations can also result in reinforcement congestion and create more challenge in construction and quality control during steel fixing.
Further challenge is the site condition did not allow for pre-drilling, and therefore polypropylene pile cannot be installed. Prefabricated steel casings with 900mm diameter were used instead to achieve the design driven depth, and auger to clean out inside the casing for 400x400mm reinforced concrete piles driven inside the casings. This also satisfied AS2159-2009 and VicRoads specification with piles driving tolerances.

Pile load testing performed to verify geotechnical strength and shaft integrity of production piles on site. Over 10% of the total number of foundation piles tested with Pile Driving Analyser (PDA), and over 6% of the total number of foundation piles subjected to CAPWAP analysis. Piles ultimate base pressure 1000-1600 kPa and integrity have been confirmed.

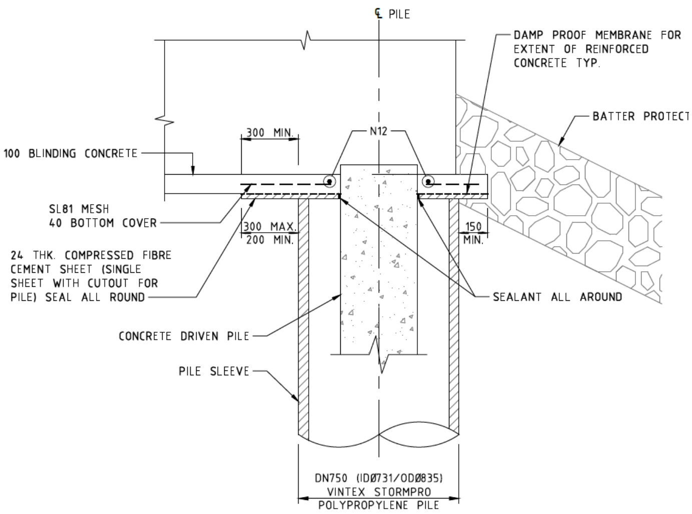

Figure 3. Halletts Way Bridge foundation details

3.4 Approach Embankment Fill

Settlement of the approach fill “causing a bump at the end of the bridge”, is a common problem for both jointed and integral abutments. However, the problem is further complicated for integral bridges because of the cyclic loading on the backfill. Often a void develops between the backfill and the abutment as the abutments move back and forth [2].

Table I. below indicates the required properties for approach fill, with a standard compaction of 98% of the backfill material to eliminate settlement of the approach fill.

Two innovations have been adopted to the interface between abutments and fill material in Fig. 4.Firstly the 40mm expanded polystyrene behind the abutment back wall. This mechanism was designed to reduce the passive earth pressure on the abutment and to help avoid the formation of a void behind the abutment to the expansion and contraction of the superstructure.

Table 1. Approach embankment fill properties

THE INTEGRAL ABUTMENT BACKFILL MATERIAL SHALL COMPLY WITH THE FOLLOWING GRADING REQUIREMENTS:

AS SIEVE SIZE (MM)	% PASSING
75	100
9.5	25-100
2.36	15-100
0.6	10-100
0.075	0-10

THE COEFFICIENT OF UNIFORMITY SHALL BE >5

LIQUID LIMIT LL (%) ≤30

PLASTICITY INDEX PI (%) <12

THE FILL MATERIAL USED BEHIND ABUTMENT SHALL COMPLY WITH THE DESIGN SHEAR STRENGTH PARAMETERS:

EFFECTIVE INTERNAL FRICTION ANGLE AT CONSTANT VOLUME = 36°

Secondly the Nylex cordrain CD1200 MF to cover the height of abutment, strip drain SD100 to cover the full width of abutment, and 100mm diameter HDPE pipe to drain downwards to the surface at toe of batter. This system will aid in carrying any water away from the abutment, and eventually decreased settlement.

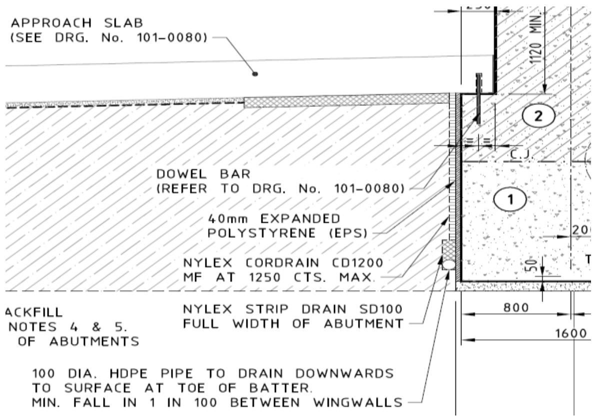

Figure 4. Halletts Way Bridge abutment fill details

3.5 Retaining wall/wing wall

As to the south abutment (Fig. 2), the retained soil adjacent to bridge abutment is not directly affected by seasonal temperature variations. Therefore, it can and should remain spatially and temporally fixed to prevent pavement settlement on the approach embankment or void formation under apporach slabs.

With integral bridges, the necessary fixity must be developed from within the retained soil itself as the abutmernts move seasonaly and no longer provide this function. Because soil with a vertical slope is not inherently self stable, this suggests that geosynthetics could be useful [7].

Reinforced Earth method is adopted in thie proejct. It is a composite material formed by the association of a frictional soil and reinforcing strips. The Reinforced Earth concept is an economical means of improving the mechanical properties of a basic material, earth, by reinforcing with another, steel.

Stresses produced within the soil mass are resisted by the strips. The stresses are transferred to the strips by friction. A Reinforced Earth structure is constructed using material shown as the 'Reinforced Earth block' in Fig. 5. Concrete facing panels are used at the face of the Reinforced Earth block to prevent erosion of the backfill and to provide an attractive finished appearance [8].

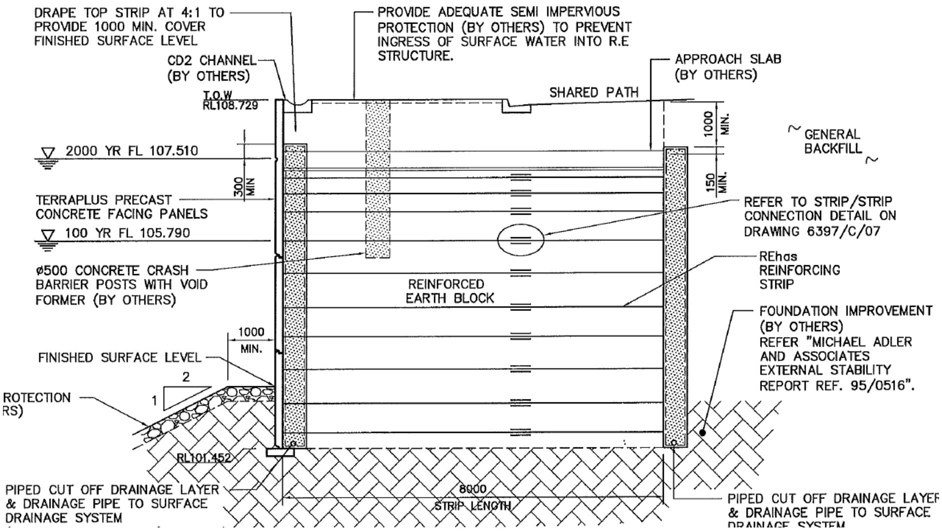

Figure 5. Halletts Way Bridge retaining wall details

The quality assurance requirement for backfill material is specified in Table II above, and III below. The select fill shall be compacted to achieve the density to a minimum of 95% of the maximum dry density as determined by AS 1289 (Standard Compaction). A Uniform density must be achieved throughout the Reinforced Earth block.

These sections of retaining wall are placed on an independent foundation, i.e. concrete leaving pad; there is no piles underneath, and no fixed connection between retaining wall and abutment. This means the retaining wall is isolated from the movement of integral abutment.

Table 2. Specification for select fill - physical properties

Requirement	Test Method	Select Fill Material Properties
Maximum Particle Size	-	Lesser of 150mm or 1/3 nominal lift thickness
% Passing 75 microns (AS) Sieve Size (Note 1)	RMS T102 & AS 1289 3.6.1	0-15 (If greater than 15% refer to Flowchart)
Coefficient of Uniformity (Note 2)	-	≥ 2
Total Compacted In-Situ Density	AS 1289 5.1.1	1.9 – 2.1 t/m³ (Unless Project Drawings indicate otherwise)

Table 3. Spec. select fill - Electro chemical properties

Requirement	Test Method	Select Fill Material Properties
pH	AS 1289 4.3.1 or, RMS T123	5 to 10 inclusive (If < 5 refer to the Flowchart 3.3)
Electrical Resistivity (ohm m)	AS 1289 4.4.1 & (Appendix B)	≥ 50 (If < 50 refer to the Flowchart 3.3)
Chloride Ion Content (% by weight) **Note 3**	RMS T1010 or, MRWA WA 910.1	≤ 0.02 (& reported to nearest 0.001%)
Sulphate Content (% by weight) **Note 3**	AS 1289 4.2.1	≤ 0.10
Sulphides Presence	TAI B117 (Appendix C)	Nil **(No sulphides permitted)**

3.6 Approach slabs

Although approach slabs are not required to be used with integral bridges in European, most countries indicated that approach slabs were desirable and the length ranged from 3-8m. This is to reduce impact forces on the bridges [1]. A buried approach slab is used in this project, at 750mm below the finished surface and covered by flexible pavement formation. This is to make settlement of the approach slab more easily repairable and may eliminate this concern.
There is a contradict suggestion that better addressed using an approach slab at pavement level with a control joint at the end of the approach slab, rather than by a buries approach slab [9]. This mainly due to lack of full understanding of abutment/fill interaction model, and also different bridge length. For short bridge there is no need for an expansion joint at his location because the movements are very small. However, in Colorado, USA, researcher reported consistent problem with the approach fill when there are no expansion joints at the end of the approach slabs [4]; this is because when bridge is in larger scale

and movement needs to be accommodated, a control joint can be used between the end of the approach slab and the adjoining pavement.

3.7 Bridge deck

Commonly, when the abutment is made integral with the superstructure, there is a possibility that during construction the superstructure will be subject to thermal movements when the freshly placed concrete of the abutment diaphragm is not full set. In Indiana USA, reporter addressed cracking occurred in the desk when the contractor poured the bent and the deck in one pour; and in New York USA, survey showed unequal deflection of stage-constructed integral bridges [4].

The Halletts Way bridge deck casting sequence is shown in fig. 6 below. The Project has cast the deck sections #1 in December 2016, and under curing for one month; prior to casting diaphragm. This is to timed such that the initial set of the abutment diaphragm concrete occurs when the superstructure is at a relatively constant temperature.

A new product Primecure 90 was used after the concrete pour on bridge deck. It is a blend of bitumen and hydrocarbon resins emulsified in water. The impervious film formed by Primecure 90 prevents excessive water evaporation. It also acts as a primer coat for future asphalt and bitumen overlays.

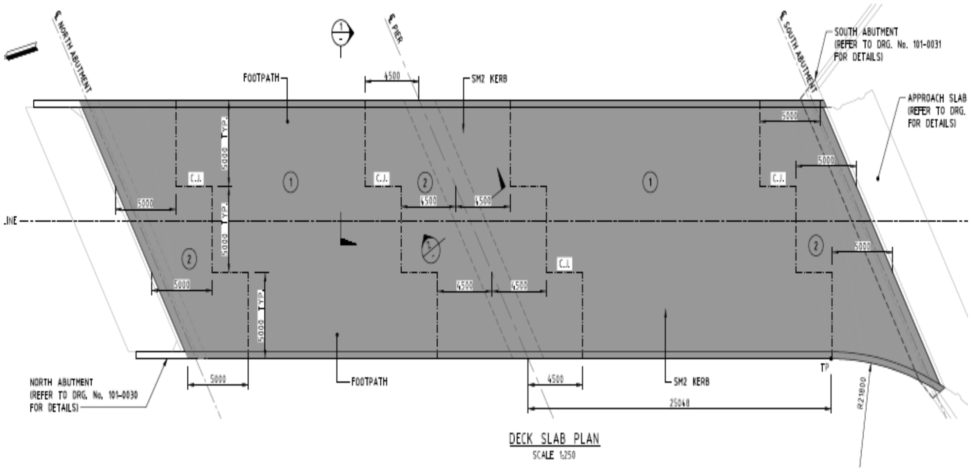

Figure 6. Halletts Way Bridge deck construction arrangement

4 CONCLUSIONS

Integral bridges present some advantages to Australian highway bridges design and construction, although not as great benefits accrued in USA or the UK due to their colder weather condition. These adorable results including initial and live-period capital cost saving, less maintenance and associated impact to traffic and society.

The quality control and innovations of Halletts Way bridge construction practice are discussed in this paper. In Australia, and other countries, integral bridges are typically designed almost empirically, using conservative methods and building on field experience. While this strategy provides safe and reliable structures, it does not forward the knowledge base on how and why integral bridges actually work. From this, there is a great opportunity for further researchers on the topic of monitoring and studying the interaction between abutment and backfill soil to understand the behavior for cyclic thermal effects under Australian conditions.

Another topic in Australian is the study on refurbishment of existing simply supported bridges into integral bridges, for their advantages described in this paper.

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