The Innovative Design of a Piled-through Mass Gravity Stone® Strong Wall for the Homestead Gully Bridge Rehabiliation, Monto

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ABSTRACT

The Department of Transport and Main Road (DTMR) commissioned the rehabilitation of the Homestead Gully Bridge which is located on Cania Dam Road north-west of Monto, Queensland. The original three span bridge consists of abutment support systems constructed in the early 1960's and was supported on driven timber piles. The newly constructed bridge consists of abutment support systems constructed of a 3.2m high mass gravity Stone® Strong retaining wall supported by 5.0m deep 600mm diameter bored piers to withstand the lateral soils pressure of the engineering fill and nominal traffic load. Bored piers were strategically positioned to prevent clashing with existing timber piles. The system was not designed to provide any structural loading support to the bridge as this was supported by H-steel piles. The soil profile consists of firm to stiff clay to 5.0m bgl followed by stiff to very stiff clay/silty clay to 14.0m bgl. This paper describes the design verification process using Ultimate Limit State (ULS) and Serviceability Limit State (SLS) methods to assess the stability and displacement of the pier supported Stone® Strong wall system.

KEY WORDS: Bridge rehabilitation, retaining walls, piled-through abutment, Stone® Strong wall

1. INTRODUCTION

1.1 PROJECT BRIEF

Homestead Gully Bridge, constructed in the early 1960's, is located approximately 6km north of the intersection of Cania Dam Road with the Burnett Highway near the township of Moonford, as indicated in Figure 1. The existing structure is a three-span bridge supported on driven timber piles with an approximate diameter of 432mm (in Figure 2). Each span is 9.14m in length. The space for the newly constructed bridge abutments was limited, thus H-steel piles was adopted to support the concrete headstock and girders through Stone® Strong the bridge abutments. An independent retaining system was required to withstand the lateral soil pressure of the engineering fill and nominal traffic load. For this reason, a 3.2m high mass gravity Stone® Strong retaining wall supported by 5.0m deep 600mm diameter bored piers was innovatively designed.

This paper presents design and construction methodology in this project, and describes the design verification process using Ultimate Limit State (ULS) and Serviceability Limit State (SLS) methods to assess the stability and displacement of the pier-supported Stone® Strong wall system.

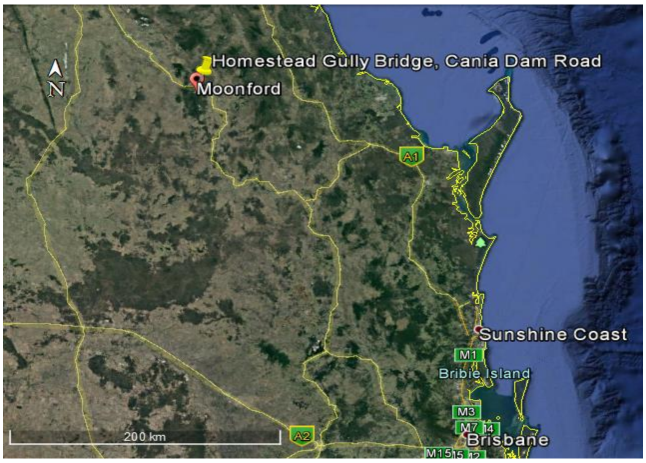


Figure 1. Project Location

Figure 2. Existing Bridge Structure

1.2 STONE® STRONG SYSTEM

The Stone® Strong system was first introduced in the United States of America in the year 2001 and was launched in Australia in 2011 with the first wall being constructed for the Gold Coast City Council by Concrib Pty Ltd. The Stone® Strong system consists of large modular precast hollow blocks suitable for gravity retaining structures up to 5.0m and RSS walls in excess of 15.0m. The standard 24SF block has a chiselled granite face area of 2.24m^2 and has a mass of 2722kg. The smaller 6SF block has a 0.56m^2 face area and has a mass of 680kg. Each block is manufactured using a minimum concrete strength of 40MPa at 28 days and are internally backfilled with aggregate or concrete to provide additional retaining wall mass.

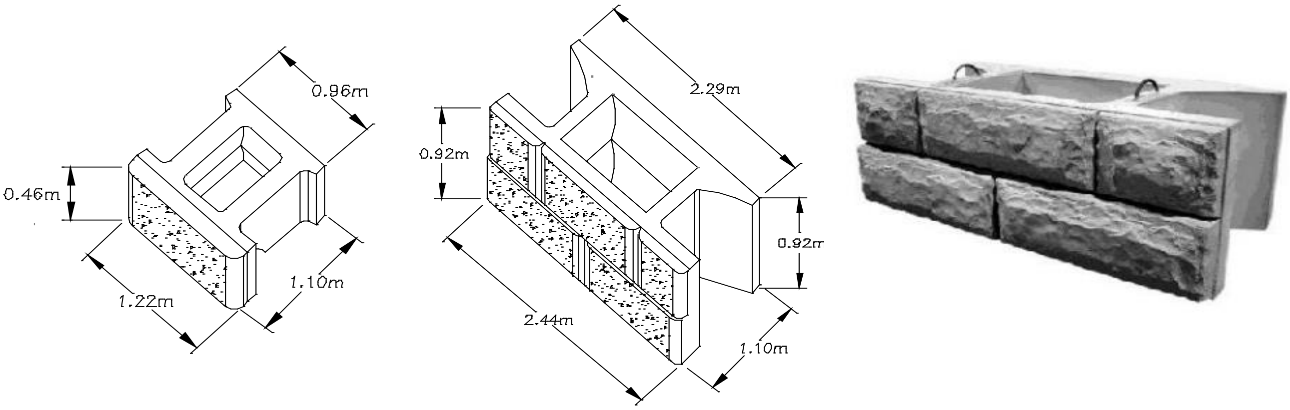


Figure 3: Typical Stone® Strong Blocks Dimension

2 DESIGN & CONSTRUCTION BACKGROUND

It is the first time this unique piled through design was adopted in Australia which could provide efficient solutions in construction for future bridge rehabilitation projects. The proposed Stone® Strong system was intended to cater for the lateral soil behind it and nominal traffic load of 20kPa, without interfering with newly constructed H-steel piles. Thus, an independent supporting system for the two abutments were required to sustain the shear force transferred from upper retaining wall. Apart from the conventional design of a Stone® Strong wall, the following considerations were incorporated during its design and construction:

- The displacement of the retaining wall is the key to secure two independent supporting systems, namely the piled retaining wall and bridge piles;

- Sufficient gap between Stone® Strong blocks and H-steel piles has to be provided during construction to ensure no load is transferred laterally to the steel piles.

3 METHODOLOGY

The piled-through Stone® Strong wall system was designed for 100 years in accordance with AS5100:2004 Bridge Design, Part 3: Foundations and Soil-Supporting Structures.

The wall system supported by bored piers is designed to restrain the lateral stress induced by the engineering fill and nominal traffic surcharge, and it is not designed to provide any structural loading support to the bridge, which will be fully supported by the steel piles.

In general, the design adopts the recommendations of partial factors in AS5100 - Part 3 and AS2159:2009. The following sections describe the adopted design methodology.

3.1 REGIONAL AND LOCAL GEOLOGY

The Homestead Gully Bridge is located in an area of Quaternary flood plain alluvium comprising of clay, silt and gravel overlying rocks of the Jurassic Evergreen Formation as indicated in Figure 4. The Evergreen Formation comprises ironstone, sandstone, and siltstone. Tertiary age basalt plug intrusions are shown approximately 2km North and South of the site. These may also be present below the site. The bridge site is located at the southern side of the alluvial plain.

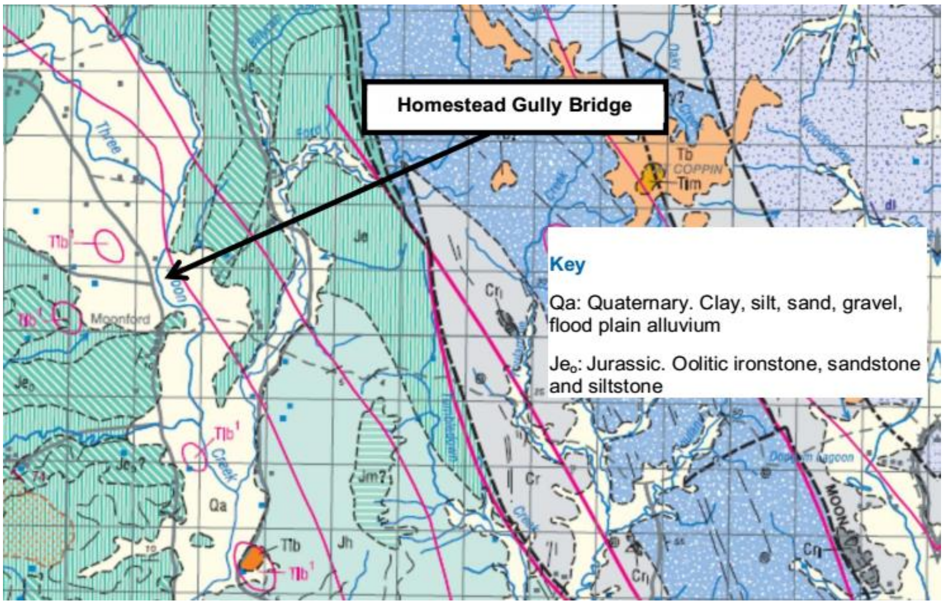


Figure 4: Local Geology

At the location of the retaining wall, previous investigations reported the entire profile as high plasticity silty clay, with approximately 2.0 - 3.7m of soft to firm silty clay overlaying 2.3 – 7.0m stiff to very stiff silty clay with no groundwater recorded. In 2014, three deeper boreholes were investigated in the close proximity of abutments, and the locations are shown in Figure 5. BH01 was adopted as the worst-case scenario in the design which was consisted of firm to stiff sandy clay / clay (Alluvium) to 5.0m bgl followed by stiff to very stiff clay / silty clay (Alluvium) to 14.0m bgl. This layer is underlain by residual soil (Argillaceous Sandstone) to the depth of 19.0m followed by moderately weathered, low strength Argillaceous sandstone to 21.0m depth. A layer of moderately to slightly weathered, low strength siltstone continues to the borehole termination depth of 25.4m.

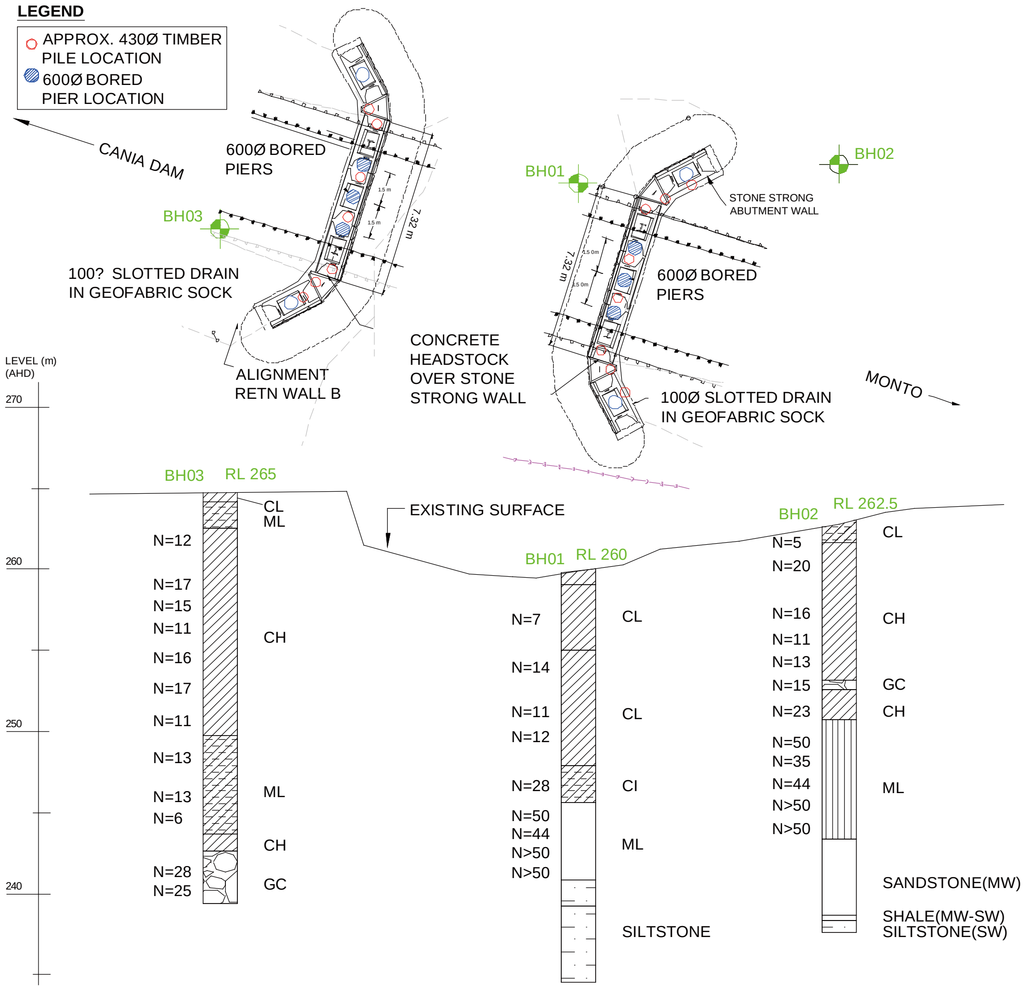


Figure 5: Plan View and Subsoil Profiles

3.2 DESIGN PARAMETERS

According to available geotechnical investigation reports and GCS's previous experience, the soil parameters adopted in the design are listed in Table 1.

Table 1 Adopted Soil Parameters

Soil Type	γ (kN/m^3)	E (MPa)	Poisson's Ratio	c' (kPa)	φ' (°)	c_u (kPa)
CLAY, grey with orange-brown mottling, high plasticity, ST-VST	19	20	0.3	5	27	96
CLAY, brown mottled, high plasticity	18	10	0.4	3	25	66
Backfill	20	30	0.3	0	30	-

3.3 STRESS BASED DESIGN APPROACH – ULTIMATE LIMIT STATE (ULS) ANALYSIS

As shown in Figure 6, lateral load behind the retaining wall comprised of soil pressure from the backfills and the transferred transportation load, while the bridge is supported by H-steel piles independently. The upper load and soil pressure acting on the retaining wall are intrinsically transferred to the 600mm bored piers below. Thus, the vertical and lateral bearing capacity check of bored piers were performed in ULS analysis. In this section, force calculation, vertical and lateral bearing capacity check are briefly introduced.

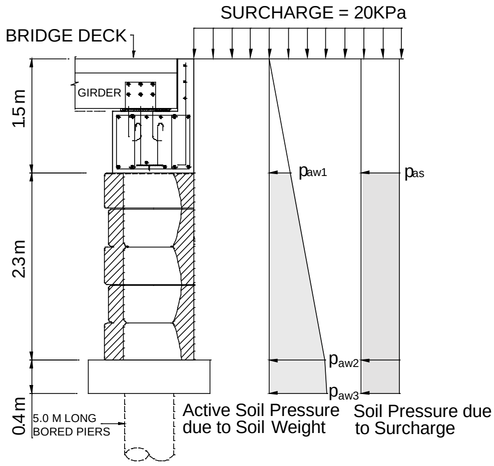


Figure 6. Earth Pressure behind the Retaining Structure

The following assumptions were made in the force calculation:

- Ground water table is assumed to be at the existing ground surface;
- A surcharge of 20kPa is assumed to be at the top of the embankment;
- Soil pressure behind the bridge headstock, as indicated in Figure 6, is not transferred to the retaining walls;
- Passive soil resistance is not considered according to Clause 13.3.1 of AS5100.3–2004.
- Sliding resistance is comprised of that from the base friction under the concrete footing and that taken by the bored piers;
- All bending moments are transferred to the top of bored piers;
- Bored piers must have spacing of 2.44m due to set block dimensions.

The sliding force due to the soil pressure behind the wall, H_f, is 62.2kN/m, and the resistance, H_{r1}, provided by the base friction under the footing is 30.34kN/m. Taking geotechnical strength reduction factor, φ_g=0.55, as recommended in AS5100.3-2004, the lateral load transferred to the bored piers, H_{r2}, is,

$$\varphi_g \times H_{r2} = H_f - \varphi_g \times H_{r1} = 45.5\text{kN/m} \tag{1}$$

Thus, the lateral force acting on each bored pier is 45.5kN/m×2.44m=111.0kN. Apart from this, the axial force and bending moment transferred to each bored pier are F = 175.0kN and M = 179.0kN·m, respectively. The calculation process of axial force and bending moment are conventional, thus no further detail is provided herein.

Brom’s method was introduced to determine the minimum length of the piers by seeking the depth where bending moment is reduced to zero.

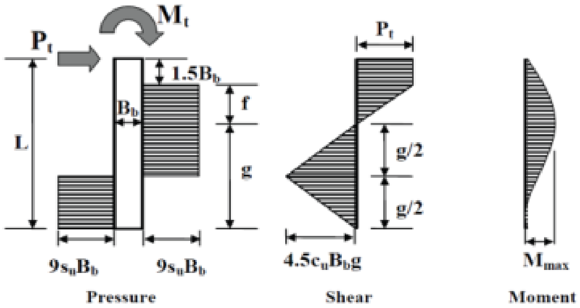


Figure 7. The Calculation Diagram of Brom's Method

In Figure 7, pile diameter, B, is 600mm, then sacrificial thickness is 1.5B = 900mm. According to bending moment calculation, the minimum length of the pier is 4.54m, thus 5.0m deep bored piers was adopted. The location of the maximum bending moment, *f*, is 0.73m, and the relevant maximum bending moment is 320kN·m.

In terms of axial capacity, undrained shear strength, c_u, is adopted to estimate skin friction, Q_s, and end bearing capacity, Q_b, of the piers. The design geotechnical strength of a pile after applying the geotechnical reduction factor, $R_{d,g}$, is,

$$R_{d,g} = (Q_b + Q_s) \times \phi_g = 574.5\text{kN} > F = 175.0\text{kN} \quad (2)$$

The piers were mainly designed to resist lateral load, thus the calculated ultimate capacity of the bored piers is much larger than the upper load, as indicated in equation (2).

3.4 STRAIN BASED DESIGN - SERVICEABILITY LIMIT STATE (SLS) ANALYSIS

The most critical part of this innovative design is to ensure no interference between Stone® Strong retaining wall and bridge support piles. This can be checked by the potential displacement of the retaining wall in SLS analysis. MIDAS GTS NX was adopted to perform SLS analysis with the same parameters listed in Table 1. The profile and the geometry of the structure was shown in Figure 8. Construction stages adopted in the analysis were as follows: (1) install piled retaining wall; (2) backfill behind retaining wall and apply transport surcharge of 20kPa. For simplification and to adopt a moderately conservative design approach, the total height of the retaining wall included the height of the concrete headstock.

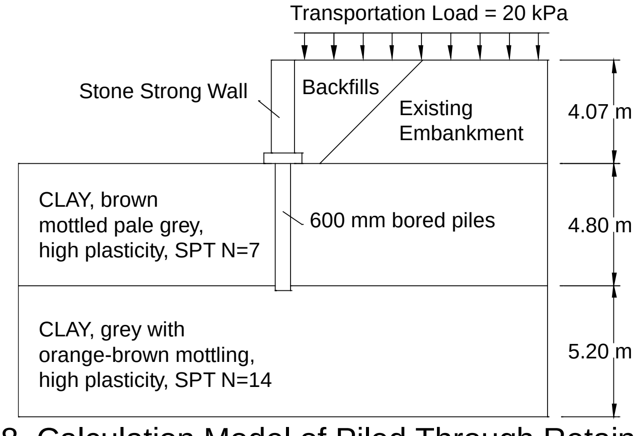
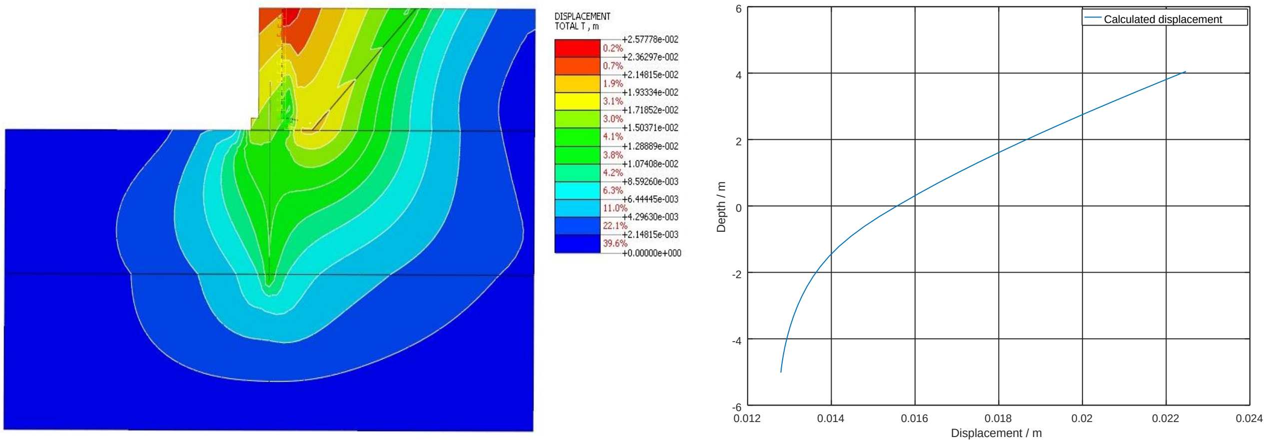


Figure 8. Calculation Model of Piled Through Retaining Wall

The calculated displacement of the studied domain and the piled retaining wall are shown in Figure 9(a) and 9(b), respectively. The maximum deflection of approximately

26mm was found on the top of the retaining wall which was acceptable when comparing to available space between Stone® Strong blocks and H-steel piles of ≈70mm. The design met the displacement criteria in ULS and SLS in ULS.



(a) Displacement Contour (b) Deflection along the Piled Wall

Figure 9. SLS Results of the Piled through Retaining Wall

4 CONSTRUCTION METHODOLOGY

RoadTek commenced construction of the piled retaining wall in late February 2016 and was completed within two months. Installation of the 5.0m deep 600mm diameter bored piers and H-steel piles commenced first. The bored piers were reinforced with 8N20 reinforcing cages extending to the same height as the first row of blocks. Once bored piers were concreted using 40MPa concrete, a 400mm thick reinforced concrete footing was cast for future block placement. The first row of Stone® Strong blocks was installed together with additional reinforcing cages which would extend through the remaining blocks to the top of the wall, as shown in Figure 10(a). Voids within the Stone® Strong blocks were filled with 40MPa concrete except for those accommodating the driven H-steel piles, as shown in Figure10(b). A 100mm diameter drainage pipe and 400mm thick drainage layer was installed behind the wall to dissipate any pore water pressures during flood events. The wall was then backfilled in layers with the concrete headstock installed above the Stone® Strong blocks as shown in Figure 10(c). The completed retaining wall system and bridge replacement is shown in Figure 11.

(a) Front View (b) H-steel Pile (c) Back View

Figure 10 Piled-through Retaining Wall during Construction

Figure 11. The Completed Piled-through Retaining Wall

5 RECOMMENDATIONS AND CONCLUSIONS

An innovative piled-through mass gravity Stone® Strong wall for the Homestead Gully Bridge rehabilitation project was introduced in this paper. This design was attentively checked in both ULS and SLS. The successful application indicates the flexibility of Stone® Strong wall to adopt different retaining methods for the abutment. The following recommendations and conclusions can be drawn in this practice.

i. The piled-through mass gravity Stone® Strong wall is an optimum option where bridge abutment is close to a waterway and only limited space can be found for construction. This design can be constructed more efficiently with lower cost comparing to conventional spill through bridge abutment wall options.
ii. This system allows construction program to be accelerated to accommodate significant and lengthy wet season for regional Central and North Queensland. Key construction elements such as Stone® Strong blocks can be pre-casted ahead of schedule, and delivered to site, hence reduce the risk of critical path from construction program.
iii. It is essential to ensure sufficient void space between Stone® Strong blocks and bridge piles. For a specific design, a displacement analysis is required to ensure no interference between a retaining wall and piles. In this design, the maximum displacement of retaining wall was set at 70mm according to the measurement of H-steel piles and blocks adopted.
iv. Benefit from the chiselled granite face of Stone® Strong blocks, this design is capable of providing an aesthetic abutment solution for small bridges.

6 ACKNOWLEDGEMENTS

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